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FREQUENCIES OF SELECTED LOW TEMPERATURES IN ALASKA*

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ABSTRACT

This report presents in detail the frequency of selected low temperatures at 33 stations in Alaska. Daily maximum temperatures at or below 0° F. may be expected over 50 percent of the days in January at interior stations and extreme northern coastal stations, but do not occur at stations exposed to the moderating influence of the ocean. The greatest frequency of maximum temperatures at or below −40° F. occurs at Umiat, where 15 percent of the days in January record this value. Minimum temperatures of −65° F. or less are recorded at only four of the interior stations.

During July, maximum temperatures at or below 68° F. occur least frequently at interior stations (13 percent of the days at Fort Yukon, 31 percent of the days at Fairbanks) and 75 to 100 percent of the time at stations exposed to maritime influence. Daily minimum temperatures at or below 32° F. in July are rare at all stations south of the Brooks Range. On the Arctic coast, in July, Barter Island and Barrow have freezing temperatures 39 and 41 percent of the time, respectively.

1. INTRODUCTION

Alaska occupies the northwestern part of North America, with the greatest portion between 60° and 70° N. latitude and 140° and 165° W. longitude (fig. 1). In addition, there are the Alaska Peninsula and the Panhandle, which extends southeastward along the Pacific coast in a strip approximately 125 miles wide. This study excludes the Aleutian Chain since extreme cold is not experienced there.

Coastal plains, river valleys, and flood plains, with elevations usually under 1,000 feet, extend over approximately one-half the area. The remainder of the region is composed of rugged mountains: the Brooks Range in the north with peaks of nearly 10,000 feet and the Alaska and Chugach Mountains in the south with several peaks reaching elevations of 15,000 to 20,000 feet.

Temperatures in Alaska are influenced by both mari-

FIGURE 1.—Station location map.

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TABLE 1.—*Mean temperatures (° F.) for selected stations in Alaska*

Station	Length of record (yrs.)	Temperature	January	July	Station	Length of record (yrs.)	January	July	Station	Length of record (yrs.)	January	July
Anchorage	23–26	Mean	11.9	57.0	Homer	8–12	23.1	54.6	Port Heiden	1– 2	29.0	52.0
	22–25	Mean max.	19.2	65.1		7–11	29.9	63.6		1– 2	34.0	57.0
	23–25	Mean min.	4.6	48.9		7–11	16.1	46.0		1– 2	34.0	46.0
Barrow	26–31	Mean	−16.7	40.0	Juneau	44–48	27.8	56.7	St. Paul Island	20–32	24.8	45.9
	25–29	Mean max.	−10.5	46.7		44–48	31.8	63.7		24–27	28.5	49.6
	25–28	Mean min.	−23.3	33.7		43–47	24.4	50.0		24–27	21.3	42.1
Barter Island	3– 4	Mean	−15.2	39.1	Kennicott	26–29	4.8	52.4	Shungnak	6– 8	1.8	58.4
	3– 4	Mean max.	−7.6	43.2		24–25	12.8	64.7		6– 8	5.9	68.6
	3– 4	Mean min.	−22.7	34.8		25	−3.2	40.4		6– 8	−9.5	48.4
Bethel	17–19	Mean	6.7	54.3	Ketchikan	30–31	33.3	57.6	Sitka	58–60	32.6	55.0
	16–18	Mean max.	15.8	62.8		23–24	39.1	65.2		44–47	38.1	61.3
	17–18	Mean min.	−0.7	46.0		23–24	29.7	50.1		44–47	26.9	48.5
Cold Bay	4	Mean	28.0	49.0	Kodiak	36–47	30.1	54.3	Talkeetna	21–24	8.3	57.9
	4	Mean max.	32.0	54.0		20–22	35.0	60.4		20–23	18.5	70.1
	4	Mean min.	24.0	45.0		20–22	25.8	47.5		20–23	−2.9	45.7
Dutch Harbor	24–26	Mean	31.9	51.3	Kotzebue	12–19	−9.6	52.5	Tanana	34–41	−12.1	58.4
	22–24	Mean max.	36.7	57.5		8–12	−1.0	57.7		33–38	−4.0	70.5
	22–24	Mean min.	27.8	45.0		8–11	−14.1	46.3		34–40	−20.9	46.2
Fairbanks	36–38	Mean	−11.3	60.0	McGrath	10	−6.7	58.7	Umiat	4– 6	−21.6	53.5
	11	Mean max.	−1.7	70.7		10	3.3	68.2		4– 6	−12.4	63.8
	11	Mean min.	−20.6	48.4		10	−16.6	49.2		4– 6	−30.8	43.1
Fort Yukon	21–27	Mean	−20.8	61.4	Naknek	13–19	14.5	54.9	Valdez	26–31	19.2	53.3
	19–21	Mean max.	−10.9	72.2		12–18	21.9	63.2		22–28	26.1	60.2
	19–21	Mean min.	−27.4	50.5		13–19	7.7	47.0		21–28	12.5	45.4
Galena	4	Mean	−9.5	59.5	Nome	34–36	3.4	49.9	Wiseman	7– 8	−11.4	55.9
	4	Mean max.	−1.2	67.1		33–35	10.6	56.0		6– 7	−2.1	67.3
	4	Mean min.	−17.7	51.8		34–35	−3.7	43.9		6– 8	−21.0	45.2
Gambell Island	4– 8	Mean	1.1	46.4	Point Hope	7– 8	−3.1	44.3	Wrangell	25–27	29.4	58.1
	2– 6	Mean max.	3.0	54.3		6– 8	4.6	50.0		17–21	35.7	66.0
	2– 6	Mean min.	−6.7	42.7		6– 8	−10.7	41.2		17–21	25.2	49.1
Holy Cross	35–44	Mean	−0.5	56.6	Point Lay	9–11	−13.3	45.9	Yakutat	18–22	29.5	52.9
	21–23	Mean max.	10.0	67.0		8–10	−5.5	53.0		17–21	34.2	58.3
	21–23	Mean min.	−5.1	47.8		8–10	−21.1	37.7		17–21	25.4	47.7

TABLE 2.—*Frequency (percent) of daily maximum and daily minimum temperatures (°F.) at or below specified values for selected stations in Alaska in January*

Station	Length of record (Yrs)	Daily maximum at or below—								Daily minimum at or below—							
		68	50	32	23	14	0	−25	−40	50	32	23	14	0	−25	−40	−65
Anchorage	23	100	100	80	54	31	6	0	0	100	99	89	66	33	3	0	0
Barrow	21	100	100	100	95	90	74	14	1	100	100	100	100	92	43	7	0
Barter Island	4	100	100	100	93	85	69	20	2	100	100	100	99	92	44	14	0
Bethel	23	100	100	79	63	52	29	4	0	100	98	88	77	54	17	3	0
Cold Bay	2	100	100	35	15	0	0	0	0	100	79	37	16	0	0	0	0
Dutch Harbor	15	100	98	23	6	0	0	0	0	100	65	21	3	0	0	0	0
Fairbanks	23	100	100	95	89	80	51	14	6	100	100	99	99	87	38	16	1
Fort Yukon	20	100	100	98	95	90	68	20	9	100	100	100	100	91	51	26	2
Galena	8	100	100	99	97	77	46	20	10	100	100	100	100	77	43	24	0
Gambell Island	15	100	100	97	86	70	30	0	0	100	100	96	86	58	0	0	0
Holy Cross	22	100	100	91	76	58	33	4	1	100	99	95	72	39	20	7	0
Homer	18	100	100	53	25	13	2	0	0	100	92	68	42	18	0	0	0
Juneau	23	100	99	45	22	6	1	0	0	100	77	43	22	7	0	0	0
Kennicott	18	100	100	82	65	47	28	1	0	100	100	93	83	58	11	1	0
Ketchikan	23	100	96	16	66	2	0	0	0	100	50	20	9	1	0	0	0
Kodiak	21	100	100	24	10	3	0	0	0	100	68	30	12	2	0	0	0
Kotzebue	20	100	100	99	86	71	46	11	1	100	100	99	94	76	30	5	0
McGrath	11	100	99	96	88	76	42	12	5	100	100	100	95	78	37	20	0
Naknek	20	100	100	64	48	33	17	0	0	100	93	77	63	38	6	0	0
Nome	23	100	100	93	68	49	25	1	0	100	99	88	75	52	12	0	0
Point Hope	7	100	100	100	82	70	45	1	0	100	100	100	95	81	27	0	0
Point Lay	7	100	100	99	89	82	67	13	0	100	100	100	96	90	48	13	0
Port Heiden	4	100	100	54	23	18	3	0	0	100	89	69	40	10	0	0	0
St. Paul Island	19	100	100	49	21	9	0	0	0	100	85	47	25	3	0	0	0
Shungnak	8	100	100	96	77	67	33	12	6	100	100	97	90	64	28	17	0
Sitka	23	100	98	18	4	1	0	0	0	100	66	25	11	1	0	0	0
Talkeetna	21	100	100	86	60	36	8	1	0	100	100	93	74	55	13	2	0
Tanana	20	100	100	100	96	86	53	13	5	100	100	99	98	84	37	19	1
Umiat	6	100	100	100	90	78	67	39	15	100	100	100	98	92	65	33	0
Valdez	21	100	100	72	34	10	1	0	0	100	100	84	59	19	0	0	0
Wiseman	16	100	100	100	90	78	44	8	2	100	100	100	99	85	33	11	1
Wrangell	23	100	97	33	11	2	0	0	0	100	74	39	21	2	0	0	0
Yakutat	17	100	100	41	11	2	0	0	0	100	87	48	27	12	0	0	0

TABLE 3.—*Frequency (percent) of daily maximum and daily minimum temperatures (°F.) at or below specified values for selected stations in Alaska in July*

Station	Length of record (yrs.)	Daily maximum at or below—				Daily minimum at or below—			
		68	50	32	23	50	32	23	14
Anchorage	21	75	0	0	0	67	0	0	0
Barrow	20	93	63	1	0	100	41	1	0
Barter Island	3	100	82	1	0	100	39	0	0
Bethel	21	80	2	0	0	86	1	0	0
Cold Bay	2	100	39	0	0	100	0	0	0
Dutch Harbor	14	100	4	0	0	94	0	0	0
Fairbanks	20	31	1	0	0	63	0	0	0
Fort Yukon	18	13	0	0	0	46	1	0	0
Galena	7	51	0	0	0	29	0	0	0
Gambell Island	14	100	67	0	0	100	1	0	0
Holy Cross	22	57	1	0	0	71	1	0	0
Homer	16	95	1	0	0	93	0	0	0
Juneau	22	79	1	0	0	65	0	0	0
Kennicott	18	68	1	0	0	100	1	0	0
Ketchikan	22	73	0	0	0	41	0	0	0
Kodiak	21	93	3	0	0	83	0	0	0
Kotzebue	18	91	14	0	0	74	1	0	0
McGrath	11	53	1	0	0	58	0	0	0
Naknek	18	84	1	0	0	87	0	0	0
Nome	22	99	27	0	0	93	1	0	0
Point Hope	8	100	54	0	0	97	8	0	0
Point Lay	3	96	38	0	0	99	10	0	0
Port Heiden	3	96	14	0	0	99	1	0	0
St. Paul Island	18	100	66	0	0	100	0	0	0
Shungnak	8	50	2	0	0	61	0	0	0
Sitka	22	98	1	0	0	64	0	0	0
Talkeetna	21	47	0	0	0	81	1	0	0
Tanana	20	40	0	0	0	70	2	0	0
Umiat	5	65	9	0	0	90	5	0	0
Valdez	19	92	1	0	0	99	0	0	0
Wiseman	15	48	1	0	0	83	1	0	0
Wrangell	21	77	0	0	0	58	0	0	0
Yakutat	18	98	1	0	0	81	0	0	0

time and continental conditions. Generally, interior valleys are the coldest areas during winter. Summers are warmest in the extreme southeastern coastal districts and in the Yukon valley. The long period of daily sunshine in summer is partly responsible for high summer temperatures, and conversely, the long periods of darkness and relatively little cloudiness in many areas during winter favor the occurrence of low temperatures.

The southern coast, on the Gulf of Alaska, is ice-free all winter and temperatures are mild compared with those farther north. During winter, along the coast from the Bering Sea to the Beaufort Sea, frozen seas result in a practically continental surface cover over an extensive area. Nevertheless, temperatures at ice-bound coastal stations do not reach the low extremes of the interior because of the heating influence of the water beneath the ice cover. In addition, greater advection near the coast prevents stagnation of air and the formation of cold pockets, and the somewhat higher vapor content of the air reduces the net loss of terrestrial radiation.

2. DATA

Data used in the preparation of this paper were obtained from publications of the U. S. Weather Bureau [1], U. S. Air Force [2] and U. S. Navy [3]. Stations were selected to provide adequate coverage of the area together with a reliable period of record. In some instances, particularly along the Arctic coast where data are scarce, it was necessary to use stations having short periods of record. The majority of stations, however, have records of over 15 years in length. Since data for some months are missing, lengths of records are provided in each of the tables presenting climatic data.

TABLE 4.—*Annual frequency of daily maximum and daily minimum temperatures (°F) at or below specified values for selected stations in Alaska*

Station	Length of record (yrs.)	Daily maximum at or below—								Daily minimum at or below—							
		68	50	32	23	14	0	−25	−40	50	32	23	14	0	−25	−40	−65
Anchorage	21–23	95	59	30	17	7	1	0	0	94	57	38	25	10	1	0	0
Barrow	19–22	99	95	72	57	46	31	3	1	100	89	68	59	46	13	2	0
Barter Island	3–4	100	97	73	58	46	32	7	1	100	87	69	60	40	20	4	0
Bethel	21–23	96	67	37	25	18	8	1	0	97	62	44	33	20	3	1	0
Cold Bay	1–3	100	82	14	3	1	0	0	0	99	42	13	3	1	0	0	0
Dutch Harbor	12–15	99	70	8	1	0	0	0	0	97	34	8	1	0	0	0	0
Fairbanks	20–23	86	61	43	35	27	14	3	1	94	65	52	45	33	11	4	1
Fort Yukon	17–20	87	68	54	44	35	22	6	2	92	68	59	51	40	17	8	1
Galena	6–8	93	67	48	37	27	14	3	1	90	63	54	54	31	13	5	0
Gambell Island	11–15	100	87	54	32	24	9	0	0	100	70	49	36	20	1	0	0
Holy Cross	20–23	92	64	39	28	19	8	1	1	95	61	46	34	21	4	1	0
Homer	15–18	99	63	19	7	3	1	0	0	98	53	28	15	4	0	0	0
Juneau	21–23	94	57	13	10	2	1	0	0	93	33	13	6	2	0	0	0
Kennicott	16–18	93	62	32	22	14	6	1	0	100	64	44	33	19	3	1	0
Ketchikan	20–23	92	47	4	1	1	0	0	0	84	20	5	2	1	0	0	0
Kodiak	19–22	98	65	8	2	1	0	0	0	95	34	11	3	1	0	0	0
Kotzebue	17–21	99	82	56	43	30	15	2	1	96	70	56	48	32	9	1	0
McGrath	10–11	91	63	43	33	25	12	2	1	95	63	52	42	30	11	4	0
Naknek	16–22	97	62	27	17	10	4	0	0	97	56	35	25	13	1	0	0
Nome	20–23	99	78	47	30	19	6	1	0	99	67	50	37	21	3	1	0
Point Hope	5–8	100	92	59	44	33	16	1	0	100	75	61	50	36	6	1	0
Point Lay	3–10	100	94	74	60	48	33	3	1	100	86	76	67	51	20	3	0
Port Heiden	2–5	99	78	28	11	5	1	0	0	99	59	33	18	6	0	0	0
St. Paul Island	17–20	100	89	21	7	3	1	0	0	100	50	19	9	1	0	0	0
Shungnak	6–8	92	71	51	37	27	14	3	1	94	69	56	45	29	14	5	0
Sitka	20–23	99	52	4	1	1	0	0	0	91	30	8	3	1	0	0	0
Talkeetna	18–21	88	58	31	17	8	2	1	0	87	63	43	30	17	3	1	0
Tanana	18–22	89	64	47	38	29	14	3	1	96	68	54	46	33	11	5	1
Umiat	4–6	96	83	67	56	46	32	11	4	99	82	69	62	51	26	12	0
Valdez	17–21	98	65	24	9	3	1	0	0	99	59	36	20	5	1	0	0
Wiseman	14–17	90	67	49	39	29	14	2	1	98	69	58	51	36	12	3	1
Wrangell	19–23	94	50	8	3	1	0	0	0	91	31	11	5	1	0	0	0
Yakutat	15–18	99	60	10	2	1	0	0	0	97	44	17	7	2	0	0	0

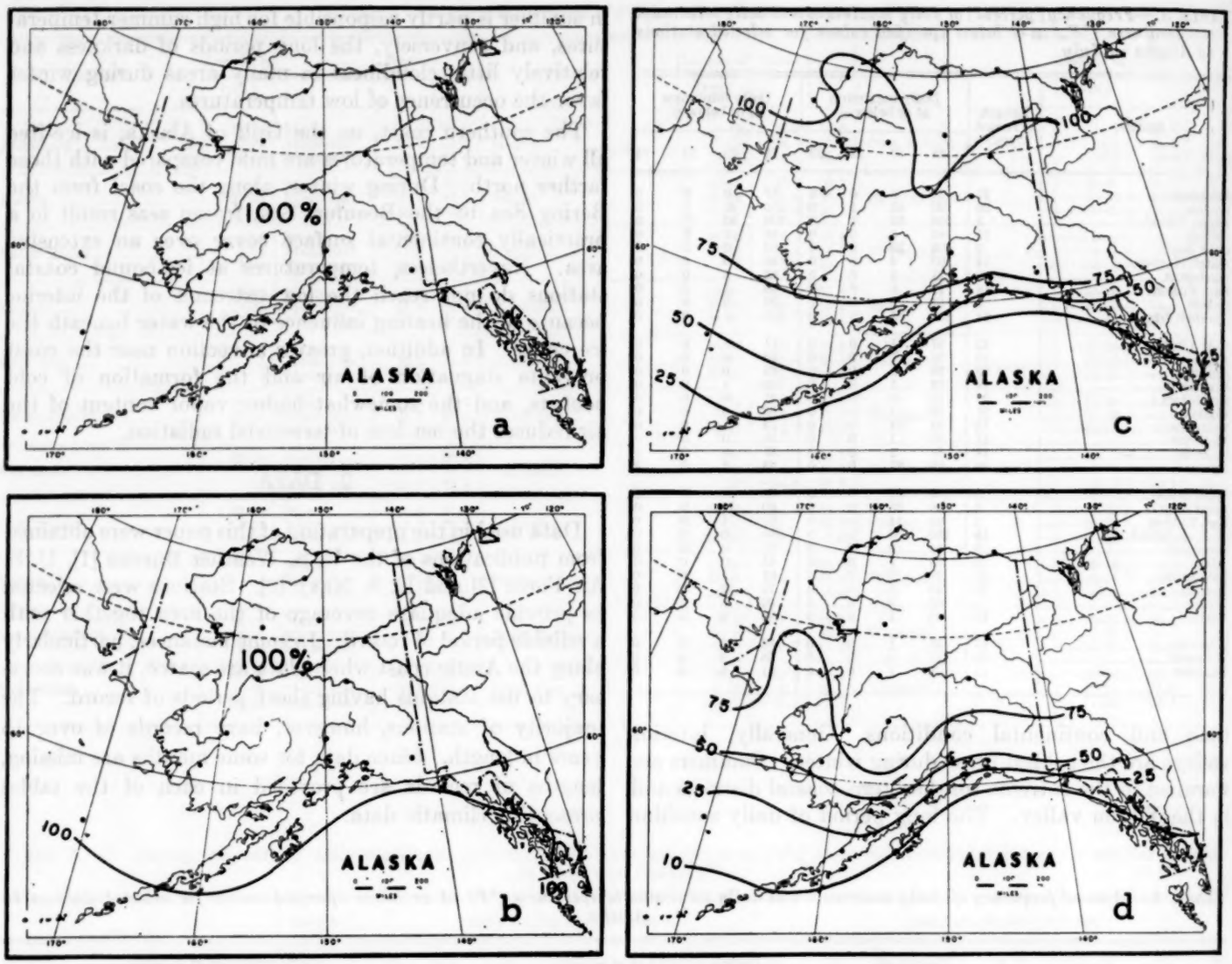

FIGURE 2.—Frequency (percent) of daily maximum temperature during January. (a) At or below 68° F.; (b) At or below 50° F.; (c) At or below 32° F.; (d) At or below 23° F.

3. MEAN TEMPERATURES

Because of its geographical position and rugged terrain, this region is subject to a variety of temperature regimes which are further influenced locally by elevation and exposure. In the interior, temperatures are often controlled by air drainage; near coasts they are more moderate due to proximity of water. Table 1 lists the mean, mean maximum, and mean minimum temperatures for January and July.

January is the coldest month at most stations. During this month mean temperatures range from −21.6° F. at Umiat on the north slope of the Brooks Range to 33.3° F. at Ketchikan on the southeast coast. Maritime influence is evidenced at Ketchikan where the difference between January and July mean temperatures is only 24.3° F. as compared to a difference of 75.1° F. at Umiat. At Fort Yukon, in interior Alaska, this difference is 82.2° F. In July, the warmest month at a majority of the stations (August is warmest at maritime stations), mean temperatures vary from 39.1° F. at Barter Island to 61.4° F. at Fort Yukon.

In the Panhandle exposed coastal stations are maritime in nature whereas temperatures of the inner parts of the islands and the mainland are influenced by their interior location. Mean temperatures in January vary approximately 5° F. (Juneau, 27.8° F. to Ketchikan 33.3° F.), stations on the coasts being warmer than those farther inland. Mean maximum temperatures in the southeastern area range from 31.8° F. (Juneau) to 39.1° F. (Ketchikan) in January and from 61.3° F. (Sitka) to 66.0° F. (Wrangell) in July. Mean minimum temperatures in January and July range from 24.4° F. to 29.7° F. (Juneau and Ketchikan) and from 47.7° F. to 50.1° F. (Yakutat and Ketchikan), respectively.

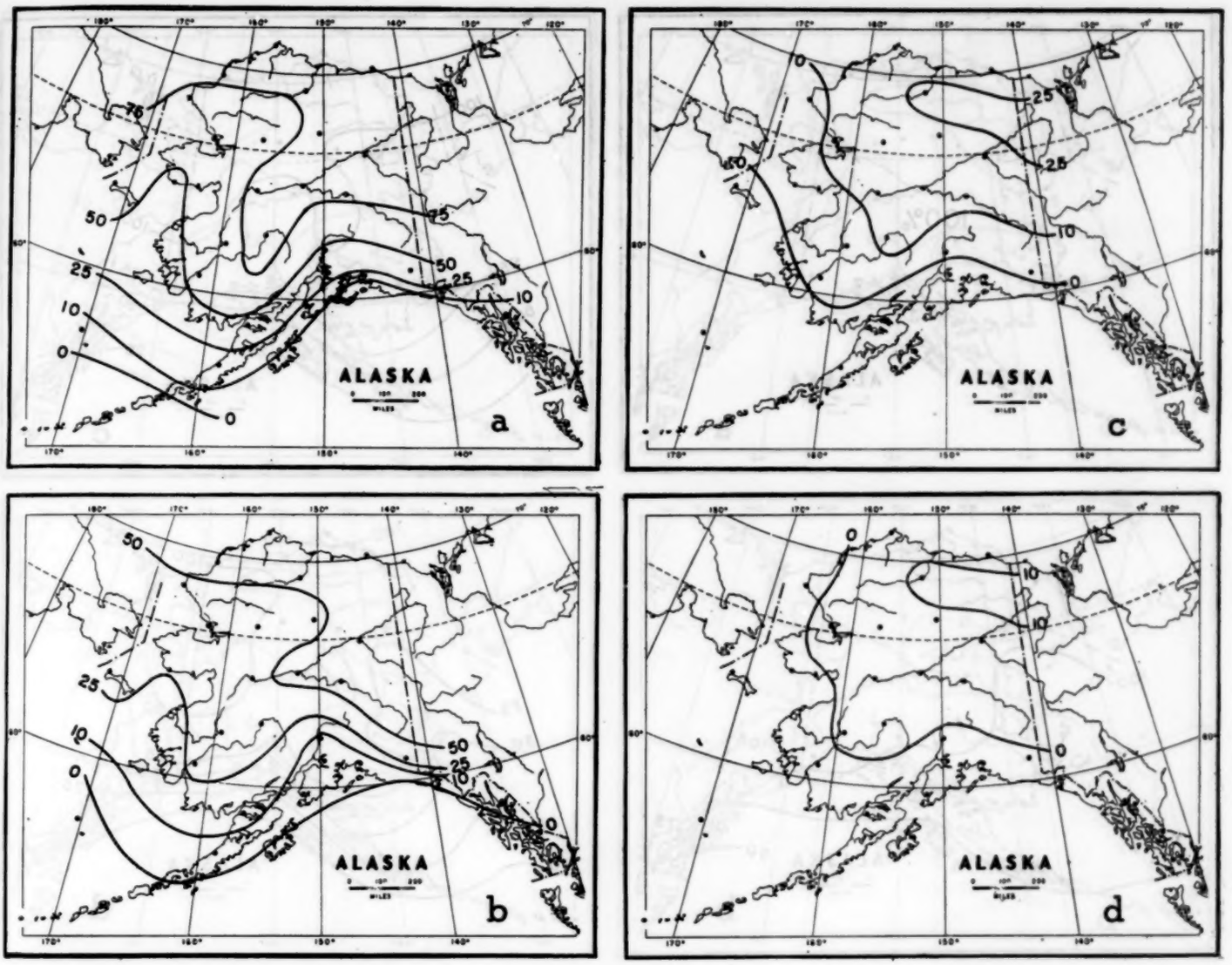

FIGURE 3.—Frequency (percent) of daily maximum temperature during January. (a) At or below 14° F.; (b) At or below 0° F.; (c) At or below −25° F.; (d) At or below −40° F.

Temperatures are generally mild on the outer coasts bordering the Gulf of Alaska and on the Alaska Peninsula. January mean temperatures range from 23.1° F. at Homer to 31.9° F. at Dutch Harbor. Farther inland it is colder; means in January range from 4.8° F. at Kennicott to 19.2° F. at Valdez. In July, mean temperatures vary from 49.0° F. at Cold Bay to 57.0° F. at Anchorage, the inner coastal stations being slightly warmer than stations more exposed to the effects of the ocean. Mean maximum temperatures in January are generally 10° F. to 25° F. higher at coastal stations than at stations in the interior, ranging from 12.8° F. (Kennicott) to 36.7° F. (Dutch Harbor). In July, the temperature progression is reversed, with mean temperatures at inland stations approximately 10° F. warmer than at well-exposed coastal stations. Mean maximum temperatures in July range from 54.0° F. at Cold Bay to 65.1° F. at Anchorage; mean minimum temperatures in this coastal region range from −3.2° F. at Kennicott to 27.8° F. at Dutch Harbor in January and from 40.4° F. at Kennicott to 48.9° F. at Anchorage in July.

Mean temperatures in January at coastal stations south of the Seward Peninsula have a range of about 11° F. Naknek, the southernmost station, has a mean temperature in January of 14.5° F. During this month mean temperatures decrease toward the north, becoming 3.4° F. at Nome on the southern coast of the Seward Peninsula. North of the Peninsula, mean January temperatures vary from −9.6° F. at Kotzebue to −16.7° F. at Barrow. Mean temperatures in July range from 39.1° F. at Barter Island to 54.9° F. at Naknek. Mean maximum temperatures are lowest along the Bering Sea coast in January and vary from −10.5° F. at Barrow to 21.9° F. at Naknek. In January, mean minimum temperatures range from 7.7° F. at Naknek to −23.3° F. at Barrow. In July, mean maximum temperatures range from 43.2° F. at

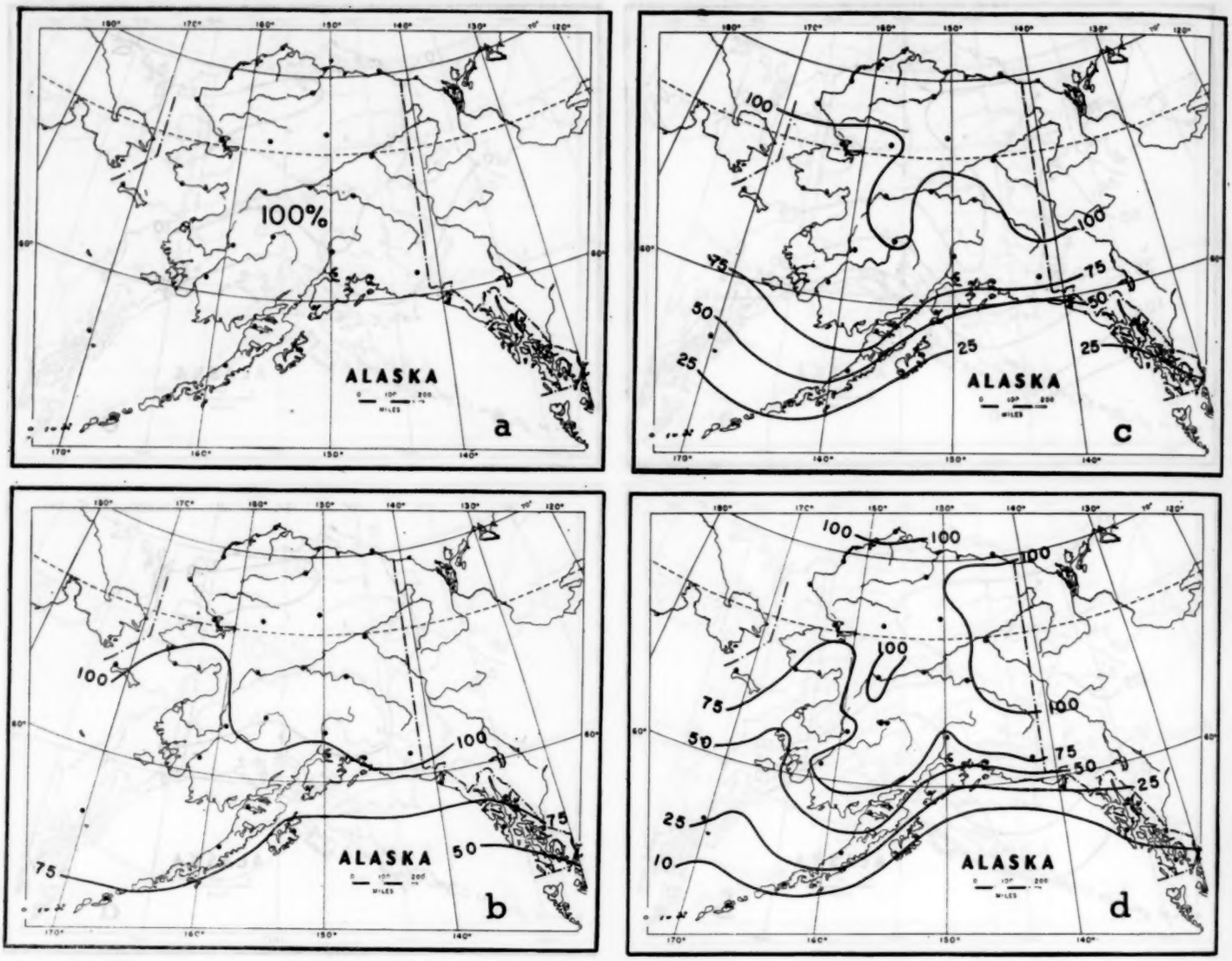

FIGURE 4.—Frequency (percent) of daily minimum temperature during January. (a) At or below 50° F.; (b) At or below 32° F.; (c) At or below 23° F.; (d) At or below 14° F.

Barter Island to a high of 63.2° F. at Naknek. Mean minimum temperatures vary from 33.7° F. at Barrow to 47.0° F. at Naknek.

Interior Alaska has, for the most part, a continental type climate. The influence of the Gulf of Alaska is rarely felt, because the mountains to the south and the Brooks Range in the north serve as barriers to maritime influence. During winter, when the Bering Sea is frozen, its influence is at a minimum; in summer, however, its effects are evidenced for considerable distances inland. Between the Alaska Range to the south and the Brooks Range to the north, mean temperatures in January vary from −0.5° F. at Holy Cross to −20.8° F. at Fort Yukon. Umiat, the only inland station north of the Brooks Range for which data are available, has a slightly lower January mean temperature, −21.6° F. In July, mean temperatures in the deep interior are considerably higher than at stations near the coast. Fort Yukon has the highest mean July temperature, 61.4° F., of all stations. Mean maximum temperatures in January range from 10.0° F. at Holy Cross to −10.9° F. at Fort Yukon. At Umiat the mean maximum temperature in January is −12.4° F. July mean maximum temperatures at interior stations vary from 67.0° F. at Holy Cross to 72.2° F. at Fort Yukon, the highest of all stations.

Mean minimum temperatures in January vary from −30.8° F. at Umiat to −5.1° F. at Holy Cross. July daily mean minimum temperatures vary from 43.1° F. at Umiat to 51.8° F. at Galena.

4. FREQUENCY OF OCCURRENCE OF SELECTED TEMPERATURES

Tables 2, 3, and 4 show for January, July, and for the year, the percentage frequency of daily maximum and daily minimum temperatures at or below the following

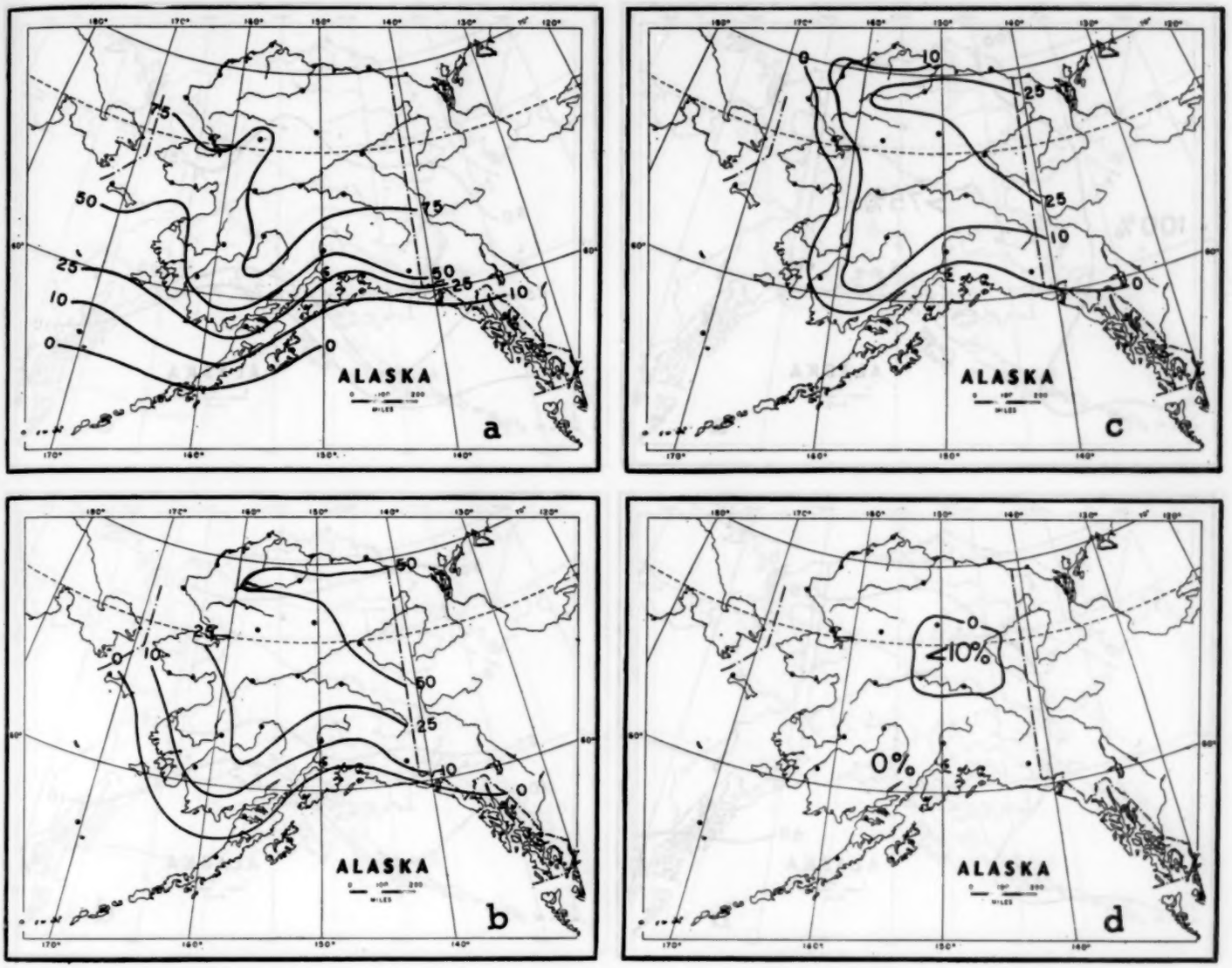

FIGURE 5.—Frequency (percent) of daily minimum temperature during January. (a) At or below 0° F.; (b) At or below −25° F.; (c) At or below −40° F.; (d) At or below −65° F.

selected values (° F.): 68, 50, 32, 23, 14, 0, −25, −40, and −65. Daily maximum temperatures at or below −65° F. and daily minimum temperatures at or below 68° F. are not included since the frequencies are 0 percent and 100 percent, respectively, at all stations in every month. Use of the tables provides detailed information of maximum and/or minimum temperature expectancies. These are of greater value and have wider application than previously discussed mean values. Data contained in tables 2 and 4 are presented graphically in figures 2 through 9. The temperature values used in this study, with the exception of 0° F., are specifically mentioned in military regulations and standards which govern the design, use, and storage of military items or are related to the issue and use of items of clothing and personal equipment.

The frequency of occurrence of maximum and minimum temperatures in the above ranges varies considerably depending to a large extent on the climatic influences at any one station.

Isolines of frequencies of daily maximum temperatures during January for each of the temperature values, are shown on maps, figures 2 and 3, and daily minimum temperatures for the same month are presented in figures 4 and 5. The annual frequencies of daily maximum and minimum temperatures for each of the values selected are presented in figures 6 through 9.

5. WINTER (JANUARY) FREQUENCIES

In January, interior and northern coastal stations are much colder than those of the southern coast, especially the Panhandle and Alaska Peninsula. Daily maximum temperatures of 32° F. or below occur only 16 percent of the time at Ketchikan and 18 percent of the time at Sitka, but occur 100 percent of the time at Barrow, Barter

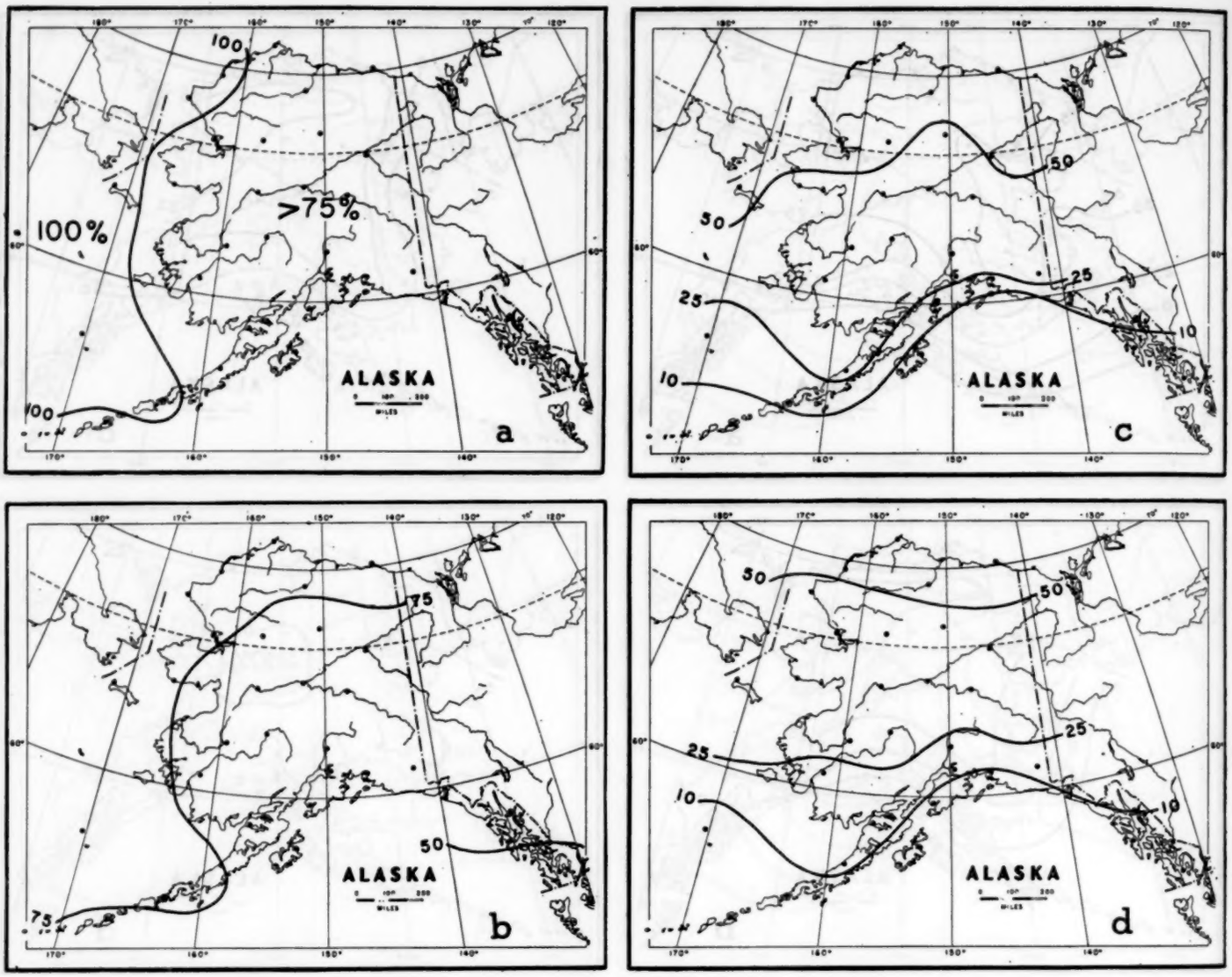

FIGURE 6.—Annual frequency (percent) of daily maximum temperature. (a) At or below 68° F.; (b) At or below 50° F.; (c) At or below 32° F.; (d) At or below 23° F.

Island, Point Hope, Tanana, Umiat, and Wiseman (fig. 2c). They may be expected over 90 percent of the time in central and northern Alaska, and even more southern stations, such as Anchorage, Bethel, Talkeetna, and Kennicott show occurrences of almost 80 percent or more.

One-third of the stations show significant frequencies (over 10 percent) of daily maximum temperatures at or below −25° F. (fig. 3c). Kotzebue and McGrath have 11 and 12 percent, respectively, while Umiat with the greatest frequency, has 39 percent (table 2). Daily maximum temperatures at or below −40° F. occur at only 12 of the stations (fig. 3b). The greatest frequencies occur at Umiat, 15 percent; Galena, 10 percent; and Fort Yukon, 9 percent. Several stations, including Barrow, Holy Cross, and Kotzebue, have frequencies of less than 1 percent.

Daily minimum temperatures at or below 32° F. occur over 50 percent of the time at all stations (fig. 4b), and over 80 percent of the time at all but 7 stations (table 2). Ketchikan, with 50 percent has the smallest percentage, and 17 of the stations have frequencies of 100 percent. Minimum temperature frequencies at or below −25° F. vary from 0 percent at Panhandle, Peninsula, southern Alaska, and island stations to a maximum frequency of 65 percent at Umiat (fig. 5b and table 2). Slightly more than one-third of the stations have frequencies of 25 percent or more during this month.

Significant frequencies of daily minimum temperatures at or below −40° F. are limited to stations in the interior, northern slope, and Arctic coast (fig. 5c). Umiat has the greatest frequency, 33 percent, and Fort Yukon, Galena, and McGrath have frequencies of over 20 percent. Daily minima at or below −65° F. are found at only 4 stations:

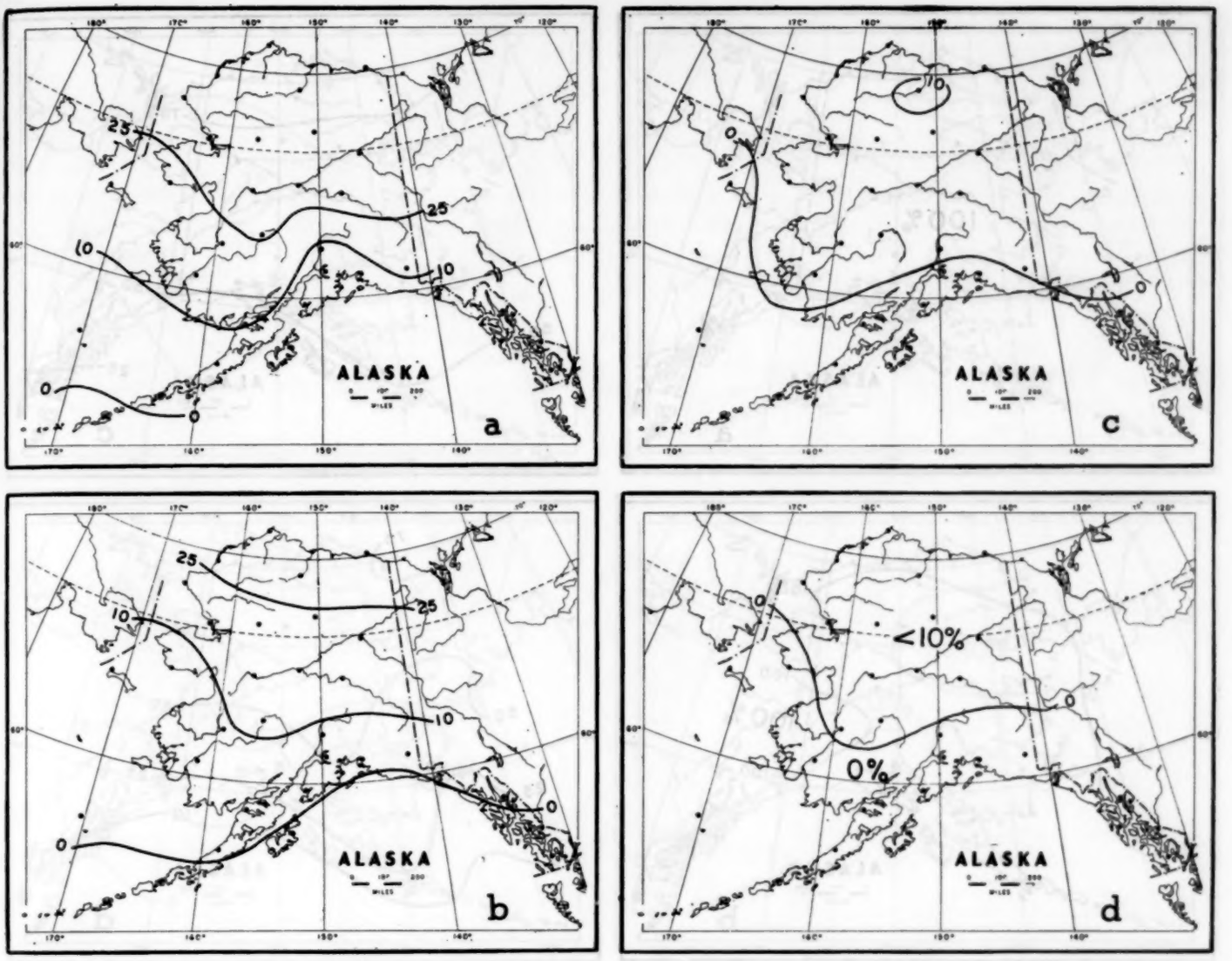

FIGURE 7.—Annual frequency (percent) of daily maximum temperature. (a) At or below 14° F.; (b) At or below 0° F.; (c) At or below −25° F.; (d) At or below −40° F.

Fort Yukon, 2 percent; Tanana, 1 percent; and Fairbanks and Wiseman, each having less than 1 percent (table 2 and fig. 5d).

6. SUMMER (JULY) FREQUENCIES

During July, daily maximum temperatures at or below 68° F. occur on 13 percent of the days at Fort Yukon and 31 percent of the days at Fairbanks, as compared to 100 percent of the days at coastal and island stations such as Barter Island, Point Hope, Gambell Island, and St. Paul Island (table 3). The latter stations have a greater percentage of temperatures below this value due to their maritime exposure. Inland stations, not subjected to oceanic influence, experience a greater percentage of temperatures above 68° F. Daily maximum temperatures at or below freezing occur only at Barter Island, 1 percent, and Barrow, with a frequency of less than 1 percent. In general, daily maximum temperatures are at or above 50° F. most of the time except at coastal and island stations of western and northern Alaska. At these stations, daily maximum temperatures are at or below 50° F. at least 14 percent of the time at Kotzebue and 82 percent of the time at Barter Island.

As mentioned above, daily minimum temperatures during July are less than 68° F. at all stations. They are less than 50° F. over 75 percent of the time except in central Alaska and the southern part of the Panhandle. Galena records only 29 percent and Holy Cross and Tanana 71 and 70 percent, respectively (table 3). This difference may be attributed to the short period of record (7 years) at Galena. In the Panhandle, a daily minimum at or below 50° F. varies from a frequency of 41 percent at Ketchikan to 64 and 65 percent, respectively, at Sitka and Juneau (table 3).

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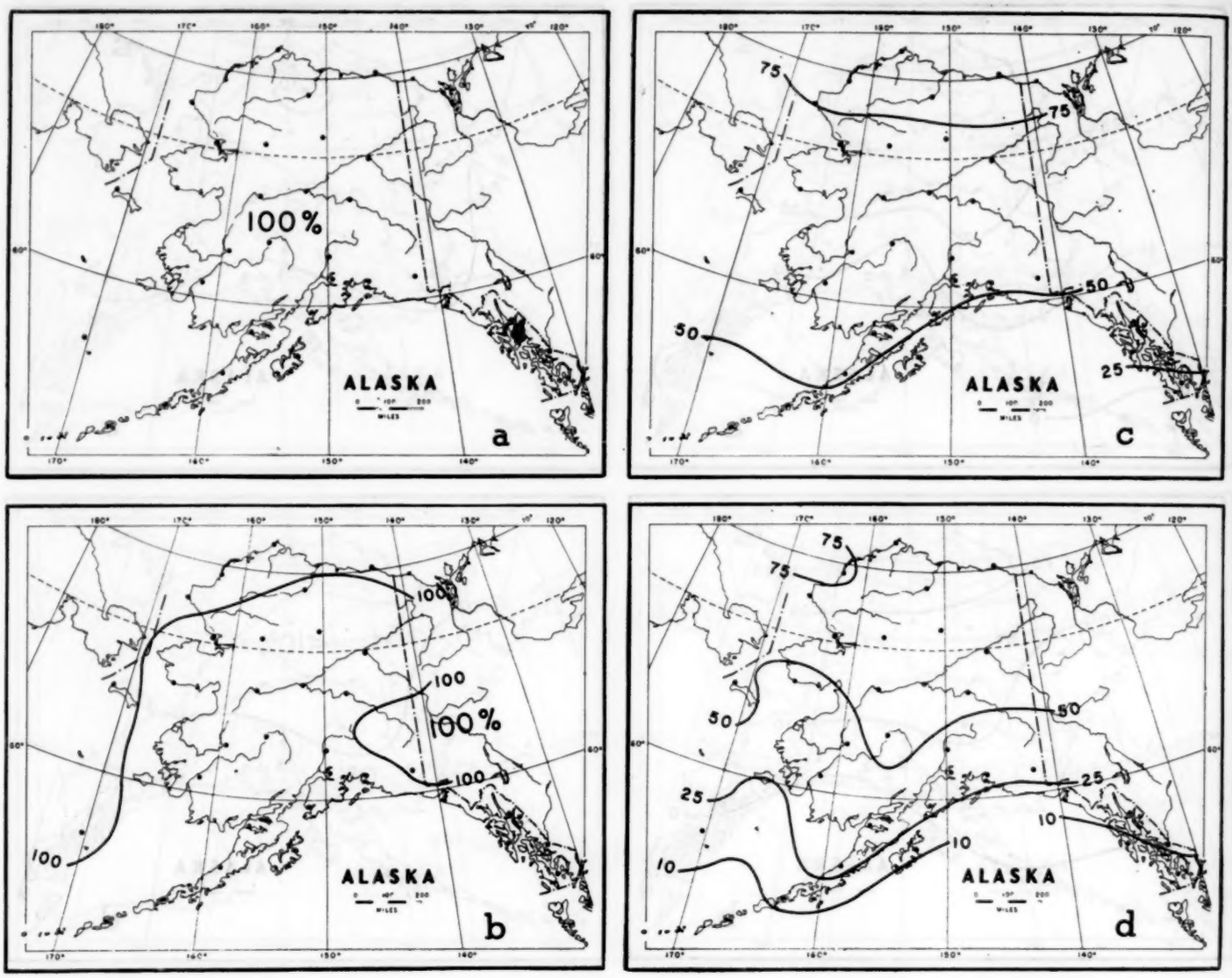

FIGURE 8.—Annual frequency (percent) of daily minimum temperature. (a) At or below 68° F.; (b) At or below 50° F.; (c) At or below 32° F.; (d) At or below 23° F.

Daily minimum temperatures below freezing in July are rare at all stations south of the Brooks Range. North of the Brooks Range, Point Hope and Point Lay have frequencies of 8 and 10 percent, respectively, while Barter Island and Barrow, with 39 and 41 percent, respectively, have the greatest occurrence. Temperatures below 0° F. do not occur at any of the stations during this month.

7. ANNUAL FREQUENCIES

Table 4 and figures 6 through 9 present information of the annual frequency of occurrence of the selected temperature values. This table, and the maps, show the average frequency of occurrence of each value during the entire year.

Daily maxima at or below 68° F. (fig. 6a) occur more than 90 percent of the time at all but four of the stations (Fairbanks, Fort Yukon, Talkeetna, and Tanana), and frequencies of maxima at or below freezing (fig. 6c) range from 4 percent at Ketchikan and Sitka in the Panhandle to 73 and 74 percent, respectively, at Barter Island and Point Lay in the extreme north. Daily maxima at or below −25° F. (fig. 7c) occur most frequently at Umiat, 11 percent, Barter Island, 7 percent, and Fort Yukon, 6 percent. Daily maxima at or below −40° F. occur at 13 of the stations (fig. 7d). Umiat has the greatest frequency with 4 percent.

Daily minimum temperatures at or below freezing (fig. 8c) occur 20 percent of the time at Ketchikan and 89 percent of the time at Barrow. In general, stations in southern Alaska have minimum temperatures at or below 32° F. for 20 to nearly 60 percent of the time, those in central Alaska, for 50 to 75 percent of the time, and north of the Brooks Range, over 75 percent of the time.

Daily minimum temperatures at or below −25° F.

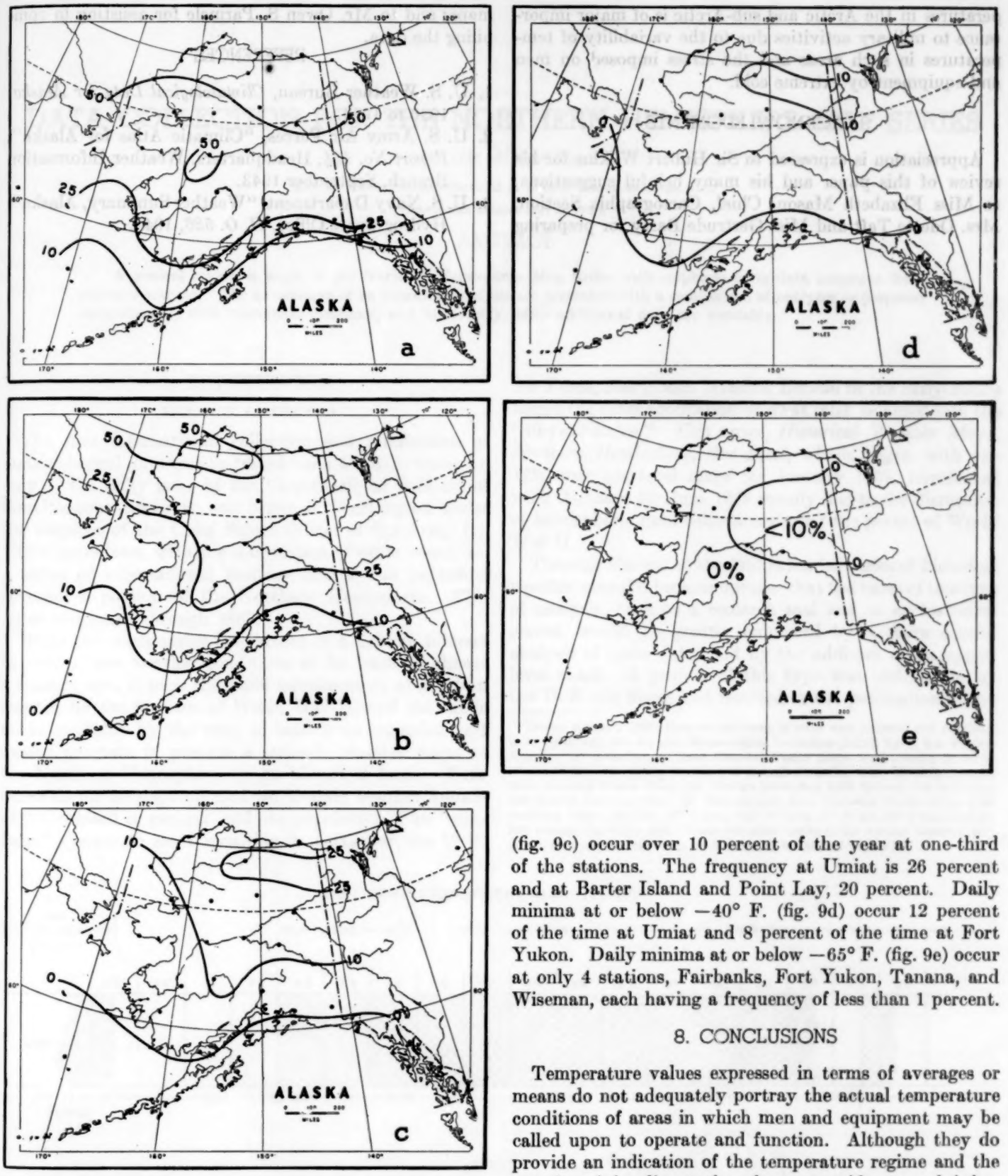

FIGURE 9.—Annual frequency (percent) of daily minimum temperature. (a) At or below 14° F.; (b) At or below 0° F.; (c) At or below −25° F.; (d) At or below −40° F.; (e) At or below −65° F.

(fig. 9c) occur over 10 percent of the year at one-third of the stations. The frequency at Umiat is 26 percent and at Barter Island and Point Lay, 20 percent. Daily minima at or below −40° F. (fig. 9d) occur 12 percent of the time at Umiat and 8 percent of the time at Fort Yukon. Daily minima at or below −65° F. (fig. 9e) occur at only 4 stations, Fairbanks, Fort Yukon, Tanana, and Wiseman, each having a frequency of less than 1 percent.

8. CONCLUSIONS

Temperature values expressed in terms of averages or means do not adequately portray the actual temperature conditions of areas in which men and equipment may be called upon to operate and function. Although they do provide an indication of the temperature regime and the severity of the climate they do not provide as much information as do tabulations of frequencies of selected temperatures. The frequency of occurrence of critical tem-

peratures in the Arctic and sub-Arctic is of major importance to military activities due to the variability of temperatures in such areas and the stress imposed on men and equipment by extreme cold.

9. ACKNOWLEDGMENTS

Appreciation is expressed to Sir Hubert Wilkins for his review of this paper and his many helpful suggestions; to Miss Elizabeth Mason, Chief, Cartographic Section, Mrs. Odette Taft and Miss Gertrude Barry for preparing maps; and to Mr. Owen S. Parmele for assisting in compiling the data.

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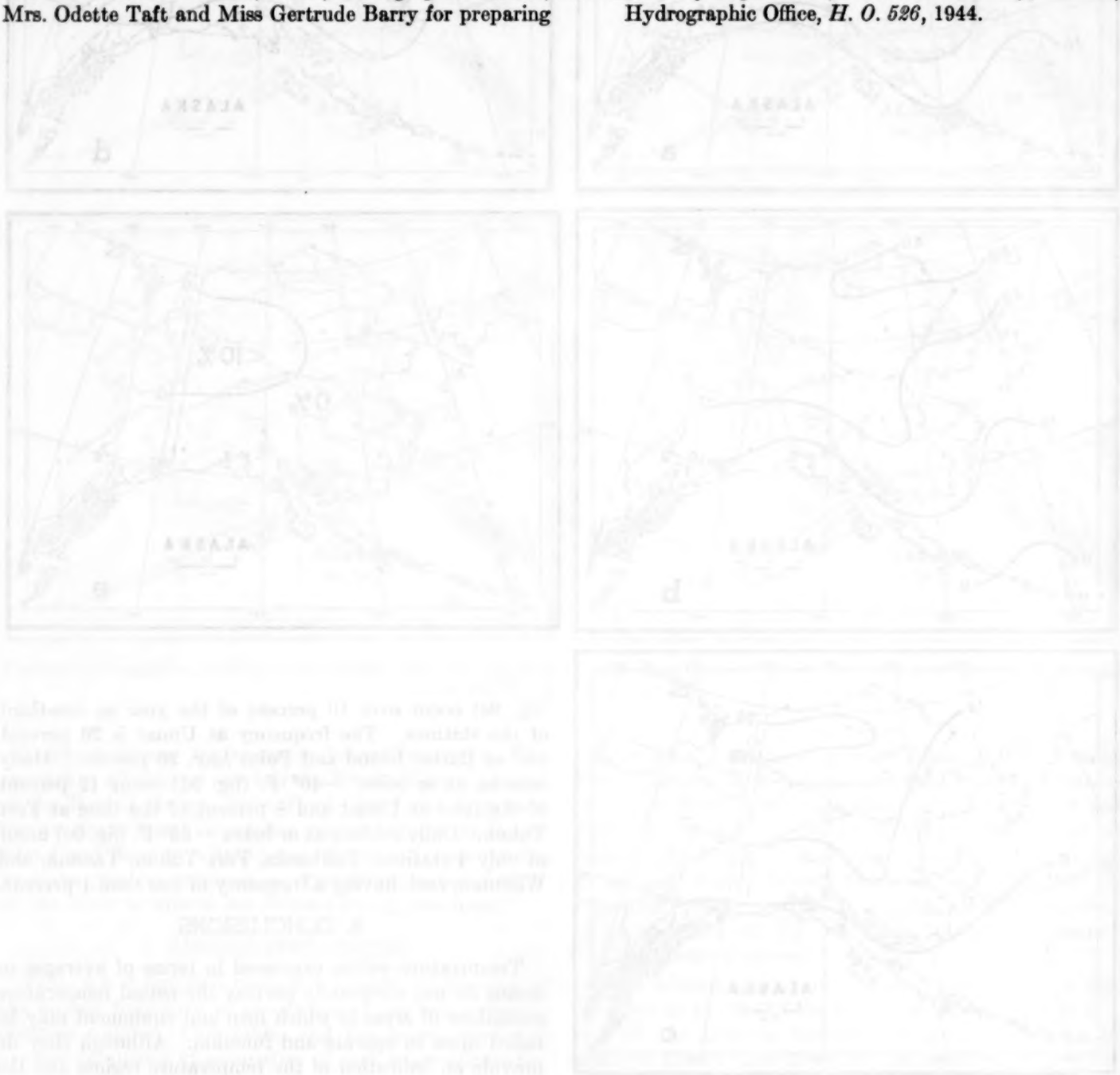
2. U. S. Army Air Forces, "Climatic Atlas for Alaska", *Report No. 444*, Headquarters, Weather Information Branch, September 1943.
3. U. S. Navy Department, "Weather Summary, Alaska", Hydrographic Office, *H. O. 526*, 1944.



DATA COLLECTION FOR THE NORTHERN HEMISPHERE MAP SERIES

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ABSTRACT

A general review is made of the Northern Hemisphere Map Series with emphasis upon data collection from multiple sources. The advantages of an historical analysis are presented with a comparison of analyses as prepared operationally, with immediate deadlines, and historically, after additional data are available.

1. INTRODUCTION

HISTORICAL BACKGROUND

The first international collection and publication of meteorological data can be traced back to 1875, when, on July 1, the daily issue of the "International Bulletin of Simultaneous Reports" was begun in Washington under the auspices of the Chief Signal Officer of the Army [1]. Three years later, with the cooperation of other countries, a series of international weather charts was published covering a portion of the Northern Hemisphere. This series continued through 1887.

While this early series is evidence of a definite interest in hemispheric weather conditions as far back as almost a century ago, it took the rapid advancement of aviation assisted by the impetus of World War II, and the funds made available by the war, to launch an extended and serious program to prepare a series of weather maps of the Northern Hemisphere on an historical basis. With demands for hemispheric and world-wide weather knowledge increased in general, and the popularity of an "analogue" system to aid forecasting in particular, the U. S. Air Force, Navy, and Weather Bureau in the early 1940's began the mass production of what later enlarged into the "40-year series." This series, *Historical Weather Maps, Northern Hemisphere, Sea Level*, which began with the 1230 GMT sea level maps for January 1899, terminated with the maps for June 1939 mainly due to the disruption of hemispheric data collection during the period of World War II.

Through the use of the first extended series of historical weather maps* it became obvious that the value of this type of analysis, both as a research tool and as an historical record, would be greatly enhanced by a more careful analysis of more data, and by the addition of an upper-level chart. A project of this type was undertaken by the U. S. Air Force and resulted in the publication of the

*During the early 1940's three shorter series of maps were prepared and published under agreement with the Joint Meteorological Committee (Army, Navy, and Weather Bureau). (1) *Daily Synoptic Series Historical Weather Maps, North America for the 10, 13, and 16 Kilometer Levels;* October 1932 through December 1940. (2) *Daily Synoptic Series Historical Weather Maps of the Northern Hemisphere, 5,000 Dynamic Meters;* October 1932 through December 1940. (3) *Daily Synoptic Series Historical Weather Maps of the Southwest Pacific, Sea Level,* 70° E Long.–145° W Long., 30° N Lat.–50° S Lat.; January 1932 through December 1934. These and other results of the wartime historical and normal map program have been summarized by Wexler and Tepper [2].

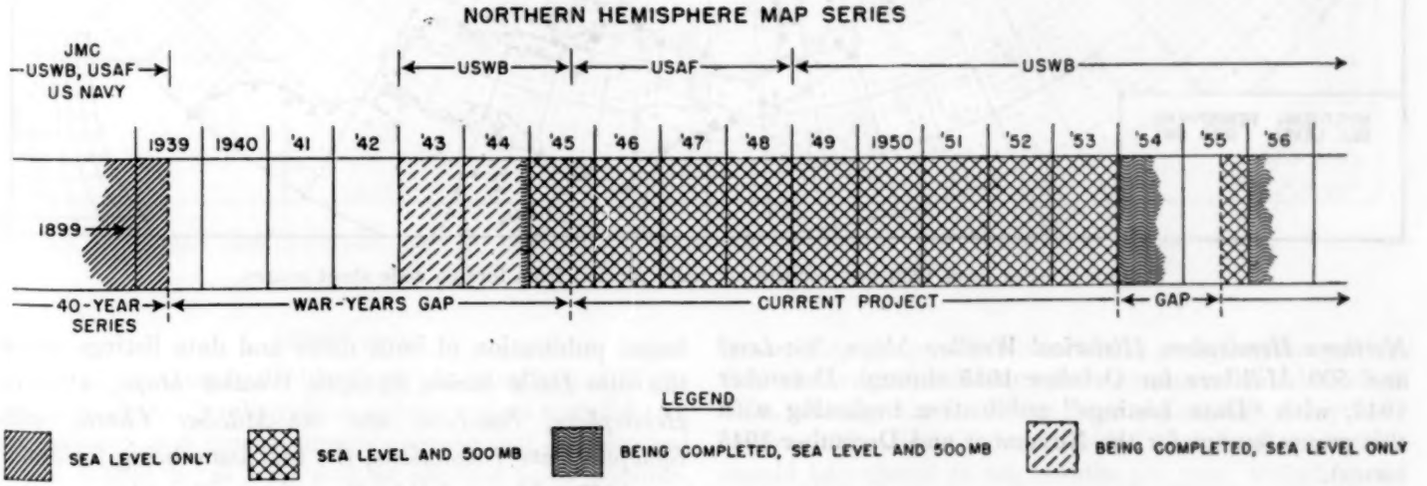

FIGURE 1.—Content and status of the Northern Hemisphere Map Series.

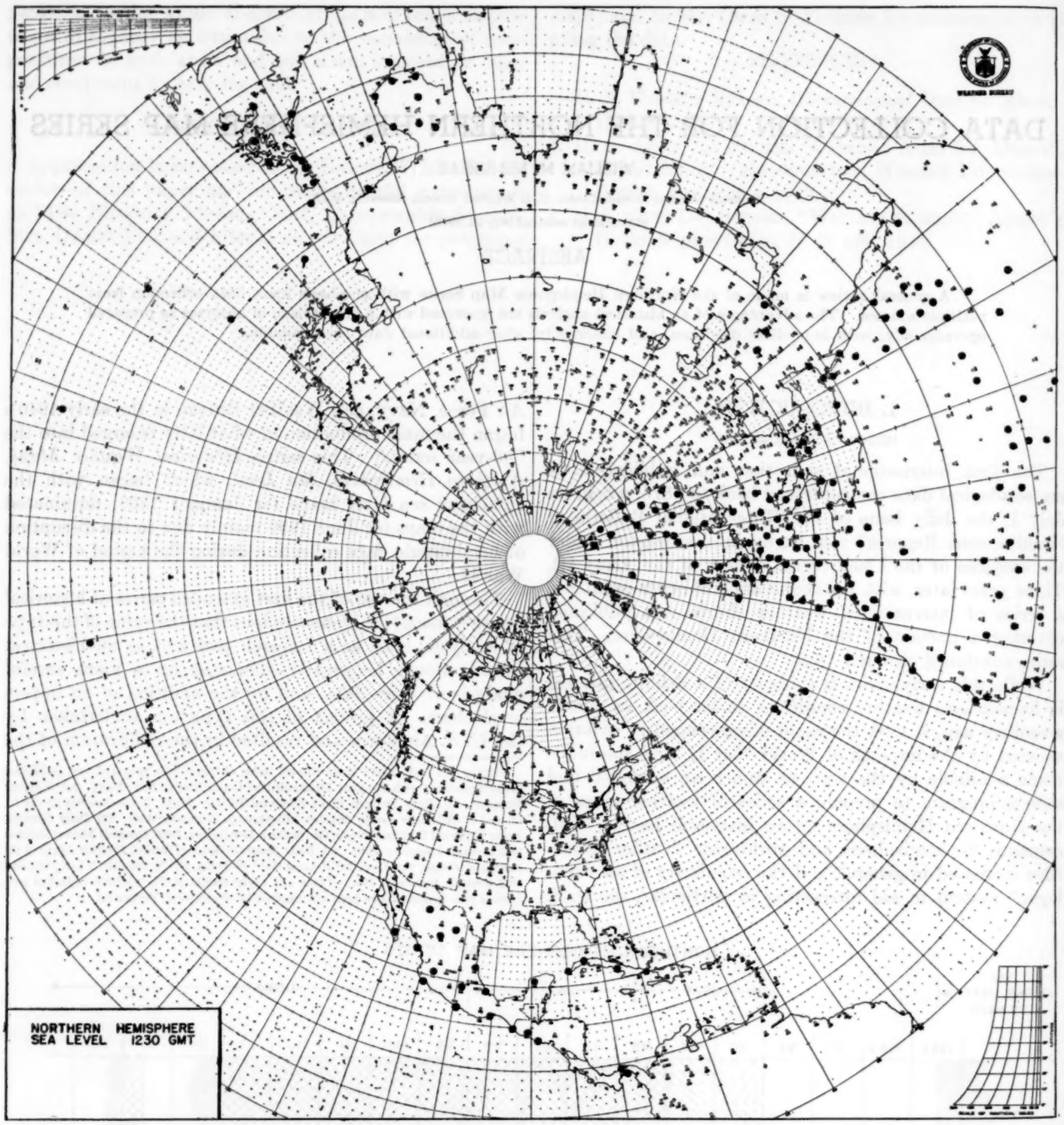

FIGURE 2.—Sea level 1230 GMT reports normally plotted from foreign code sheet source.

Northern Hemisphere Historical Weather Maps, Sea-Level and 500 Millibars for October 1945 through December 1948, with "Data Listings" publication beginning with this group (except for the November and December 1945 issues).

In the early months of 1949 new financial life was given to the project, and with the help of funds transferred from the U. S. Air Force and Navy, the Weather Bureau again began publication of both maps and data listings under the title *Daily Series, Synoptic Weather Maps, Northern Hemisphere, Sea-Level and 500-Millibar Charts, with Synoptic Data Tabulations*, the first issue being for January 1949. Most of this discussion will pertain to this "current" project, with emphasis on the July 1955 and subsequent issues.

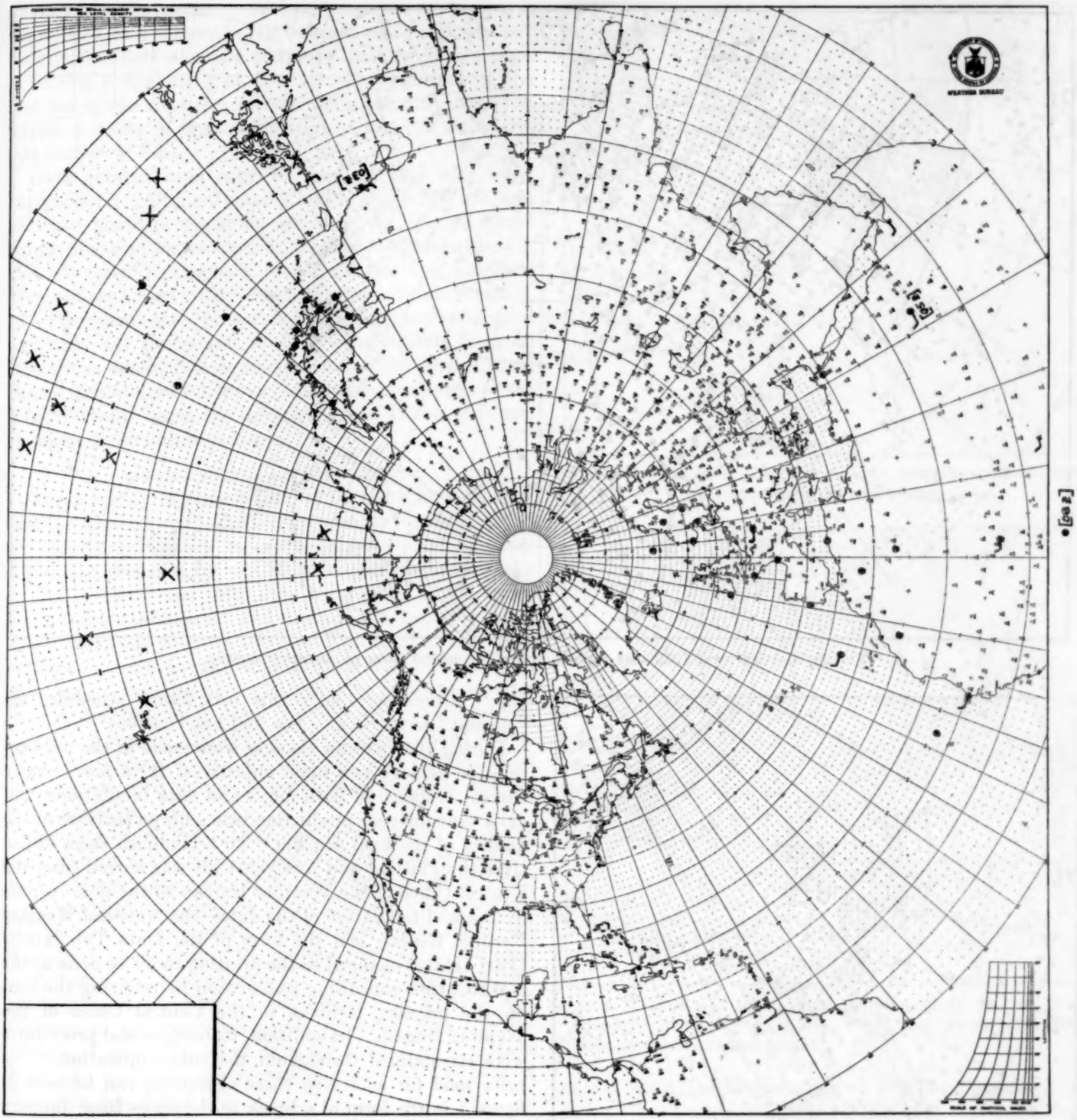

FIGURE 3.—500-mb. 1500 GMT reports normally plotted from foreign code sheet source. "X" plotted from original records. Wind barb shows pibal data only received from that station.

CURRENT SERIES

From the viewpoints of both an historical record of the weather of the Northern Hemisphere and as a useful tool for research, it is most commonly agreed that an historical series should be as long and as continuous as possible. Soon after the re-birth of the main series (January 1949) it became evident that due to irregular financial support it would not be possible to achieve a year-for-year production of the analyzed maps and companion tabulations of data. Rather than sacrifice the completeness and quality of the publications, it was decided that final production should be reduced to ten months per year, accepting the unavoidable and ever-growing backlog in the hope that facilities would sometime become available to "fill the

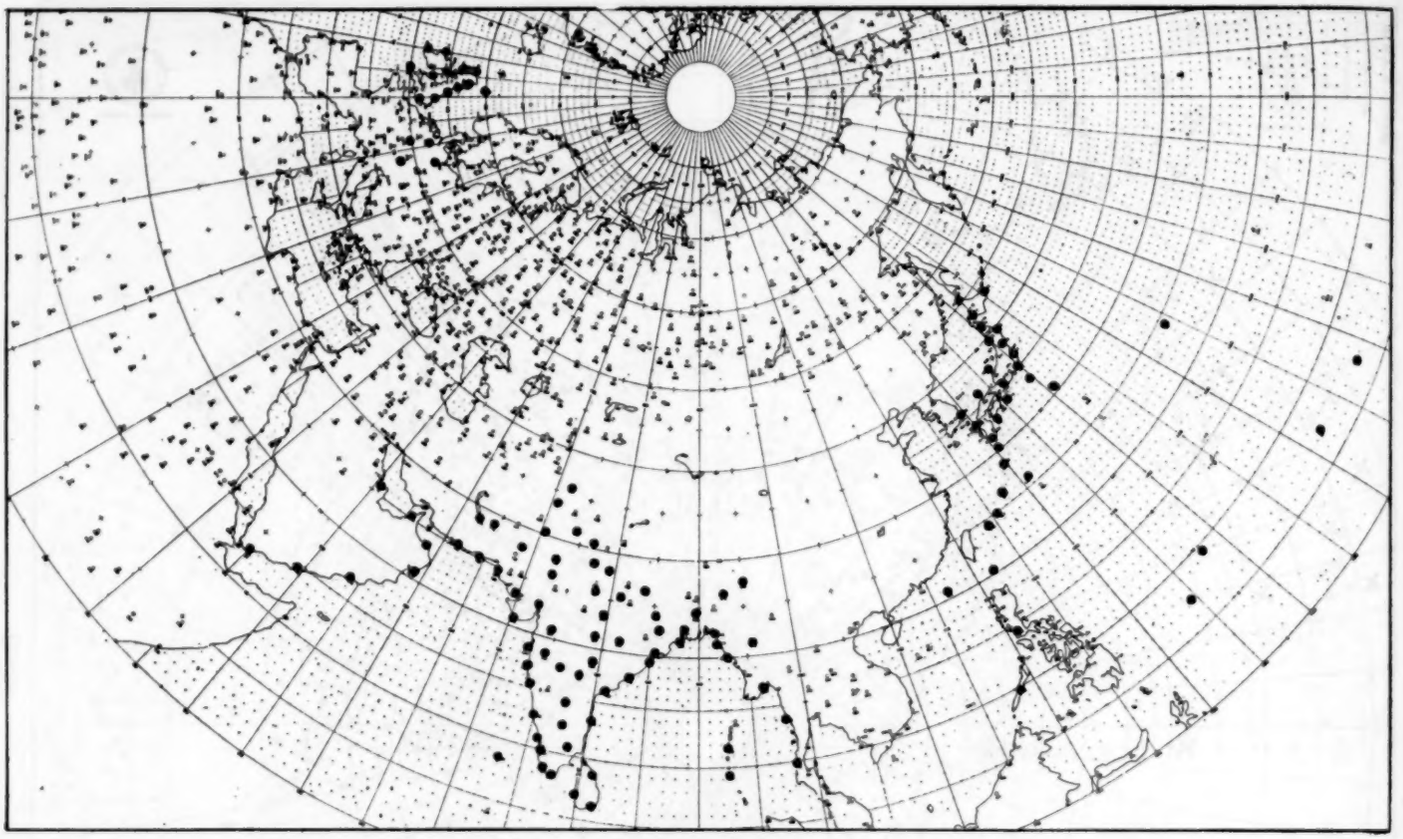

FIGURE 4.—Sea level 1230 GMT reports normally plotted from publications source.

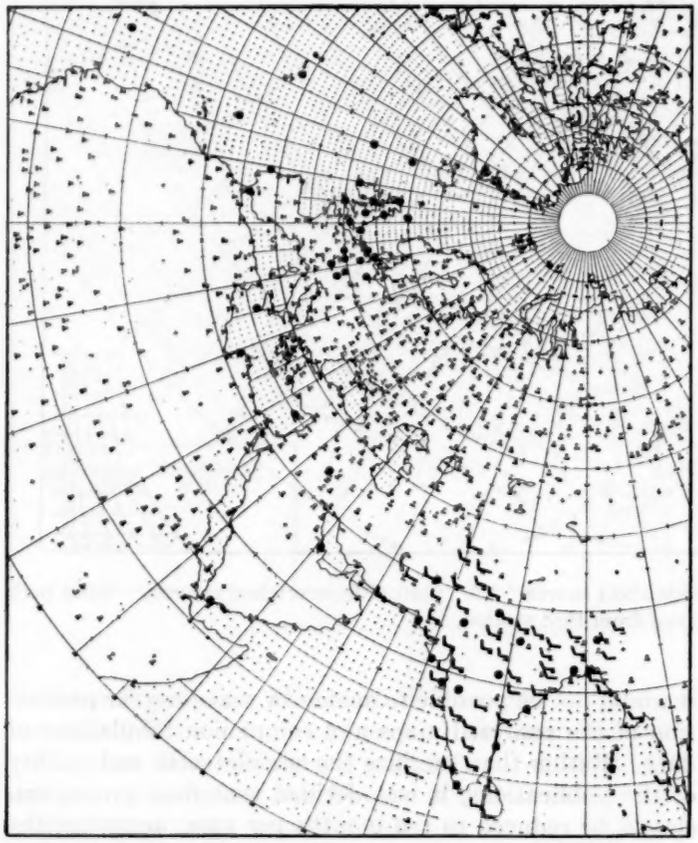

FIGURE 5.—500-mb. 1500 GMT reports normally plotted from publications source. Wind barb shows pibal data only received from that station.

gap." Operating under this production schedule, the "current" series became less and less "current".

During 1955 certain changes were made in the publications to achieve two main objectives: (1) a more nearly current issuance of both maps and data tabulations, and (2) a year-for-year production rate with no sacrifice of the quality of the final product. To accomplish these objectives the Plotting and Analysis Unit was moved from the Central Office of the Weather Bureau to the point of collection and tabulation of the data—the National Weather Records Center, and the form of the Data Tabulations (Part II) was changed so the printing could be done at the NWRC, thus expediting publication by relieving the load on the printing facilities in the Central Office of the Weather Bureau. In addition, techniques and procedures were streamlined throughout the entire operation. The price paid for achieving these objectives can be seen in figure 1 in the form of a break in the series from January 1954 through June 1955. However, with the help of funds transferred from the U. S. Air Force and Navy, analysis of maps to fill both this gap and the war-years gap is now progressing. It is planned to publish issues for these periods as facilities permit.

2. DATA COLLECTION

GENERAL

One of the advantages of an historical analysis and data listing program is the elimination of the restriction of only a few hours allowed for data collection by teletypewriter until analysis begins—as is necessarily the case in

all operational programs. Although the current project is committed to a 6-months lag between calendar date and distribution date of maps and data listings, some phases of editing and plotting of data actually begin during the first few weeks after the calendar date, and may extend to within 6 weeks of final publication in cases of unusually late receipt of data.

Data sources used may be grouped into four main categories: (1) Original records on file at the NWRC, and punched cards prepared on station. (2) Special report forms prepared by cooperating meteorological services in the Northern Hemisphere specifically for the Northern Hemisphere Series (referred to hereafter as "code sheets"). (3) Published data prepared by foreign meteorological services. (4) Radio and teletypewriter reports from all collections available including those received in the United States on standard teletypewriter and those shipped to the United States which are interceptions of Union of Soviet Socialist Republics broadcasts.

ORIGINAL RECORDS AND PUNCHED CARDS

The majority of reports for the United States, Alaska, and the Atlantic and Pacific ocean weather vessels operated by the United States, are acquired from punched cards which are prepared on station and checked for accuracy at the NWRC. Sea level data are plotted on the maps from these tabulations, and although it is not feasible operationally to plot the 500-mb. data from similar tabulations, these listings and original records are available as a data source in cases of a total absence of teletypewriter data or for checking in cases of dubious individual reports (see figs. 3 and 10). In addition to those mentioned above, punched cards prepared by Mexican and Pacific island stations are used in the preparation of the data listings for publication.

About half of the marine sea level reports used are plotted from tabulations of original ship weather observation logs which are received and processed at the NWRC.

Through the cooperation of the Canadian Meteorological Service, it has recently become possible to list in the Tabular Data section of the current publication, sea level and upper air observations for Canada from punched cards prepared in Canada and shipped to the NWRC. Because of the many problems connected with this exchange of data, Canadian data are plotted on the maps from the standard teletypewriter source at the present time (see figs. 9 and 10).

Because of the scarcity, and therefore greater relative importance, of upper air observations from the Pacific, available reports for the 500-mb. maps are plotted from original records (adiabatic forms with pressure-height computations) from these reporting stations (see fig. 3).

CODE SHEETS

Because of the desirability, from both an analytical and a climatological standpoint, of the regular receipt of sea level and upper air reports from the same stations, a program of data collection by use of special forms sub-

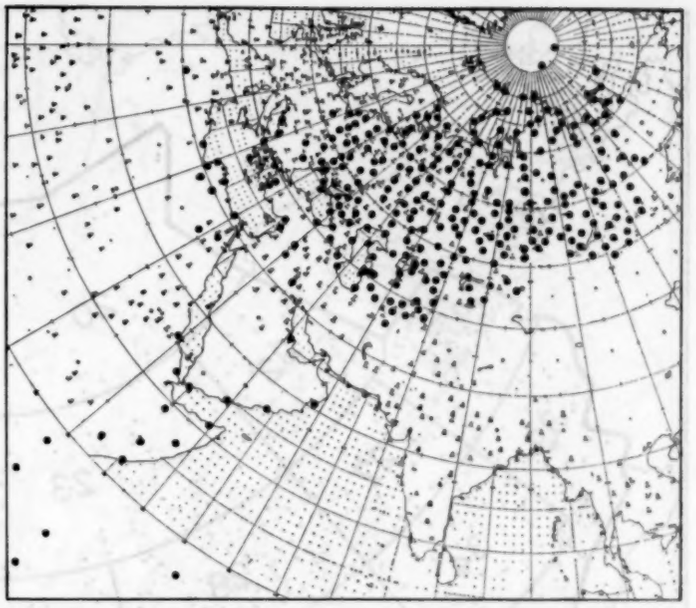

FIGURE 6.—Sea level 1230 GMT reports normally plotted from intercept teletypewriter source.

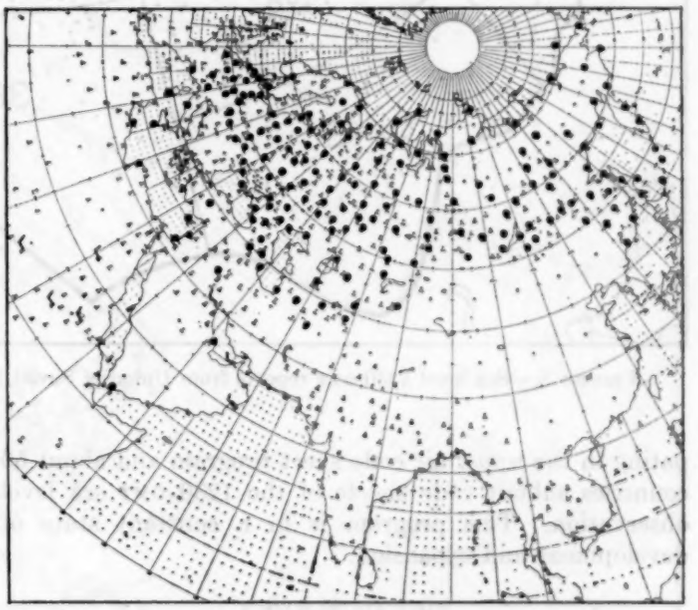

FIGURE 7.—500-mb. 1500 GMT reports normally plotted from intercept teletypewriter source. Wind barb shows pibal data only received from that station.

mitted with the cooperation of foreign meteorological services has been developed. While code sheets for only the 1230 GMT sea level observation are received, intermediate hours of radiosonde (including in some cases rawins and standard and significant level reports) and pilot balloon observations are received by mail on monthly forms. Reports plotted from this source are shown in figures 2 and 3. Of course, the stations shown send reports in this manner for the particular time and level of the maps; these reports in addition to reports for all other times and levels recorded are listed in the Data Tabulations. At present, about 40 foreign services are partici-

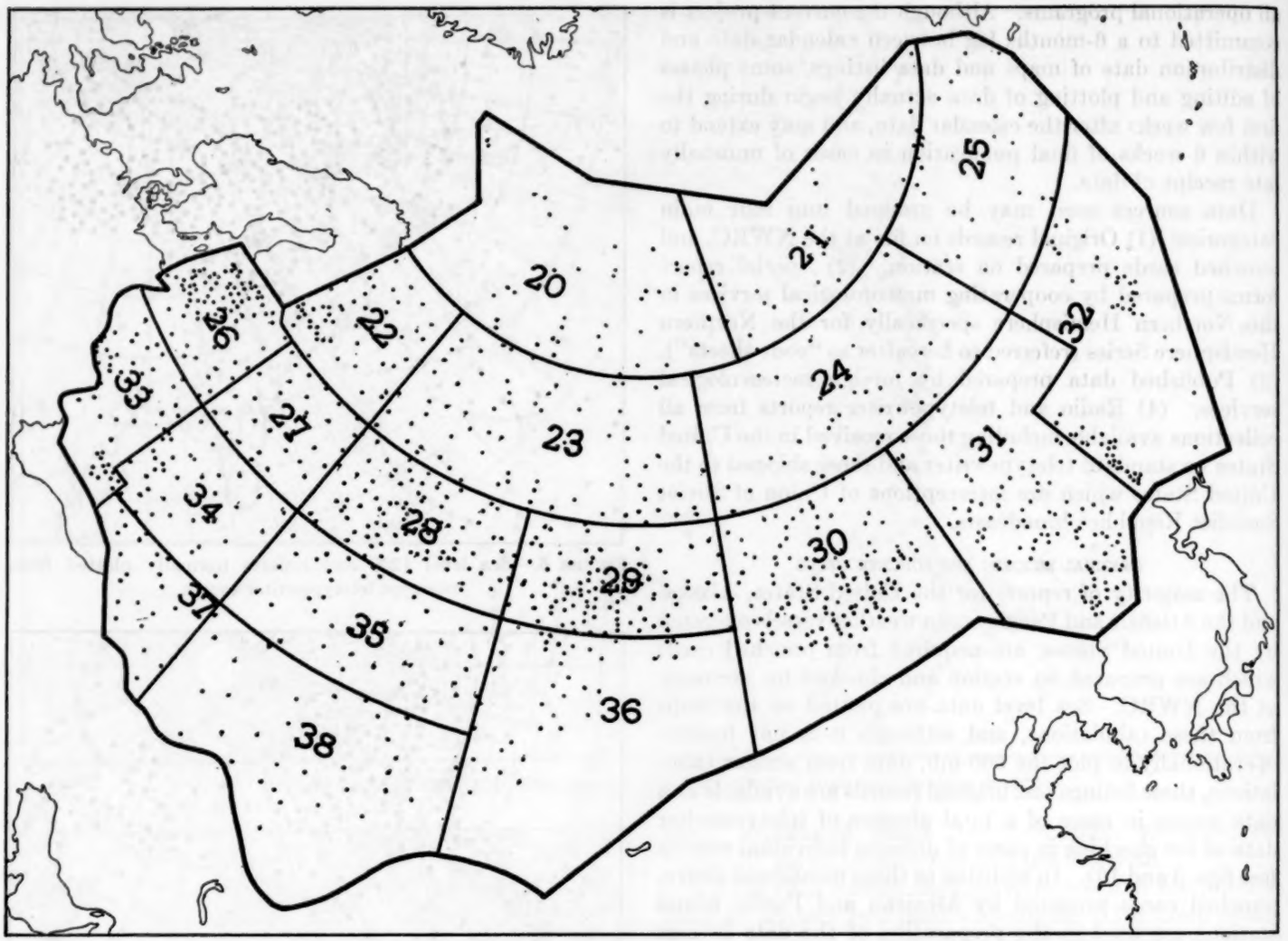

FIGURE 8.—Sea level 1230 GMT reports from Union of Soviet Socialist Republics available from intercept teletypewriter source.

pating in the upper air code sheet program and about 50 countries submit code sheets of the 1230 GMT sea level observation. This program is in a constant state of development and expansion.

PUBLICATIONS SOURCE

While many countries issue publications of meteorological data, the extremely wide variance of types, times, codes, and methods of presentation of these data makes it impossible to utilize all of the different publications or, in some cases, even all of the data in one particular publication. Many of these published reports include analyzed charts of many descriptions, and these are used as reference material during the analysis. Reports as shown in figures 4 and 5 are plotted from meteorological data published by Germany (including ship observations), Great Britain (including the Overseas Supplement to the Daily Weather Report), India, Japan, Portugal, Pakistan, Switzerland, and Malaya. Where practicable, data included in these sources are transferred to punched cards and included in the Data Tabulations.

TELETYPEWRITER SOURCE

As is shown in figures 6 and 7, the bulk of reports from the Soviet Union are received by radio teletypewriter. While these reports are received in the United States by a multiple relay system, the availability of the "intercept teletypewriter" source used is made possible through the cooperation of the U. S. Air Force installations in Germany, Japan, and Arabia, and a similar intercept station in Alaska operated by the Civil Aeronautics Administration which intercept broadcasts of weather reports made from the Soviet Union. While these reports are relayed on a regular schedule to the United States by radio, and then relayed by land-line teletypewriter to points within the United States, the originally intercepted material in teletypewriter form is eventually shipped to the NWRC, and this "original" material is then available for use by the Northern Hemisphere Project. Because of the elimination of the relays necessary to transmit these data from the overseas intercept points to stations within the United States, this intercept teletypewriter affords the most complete and consistent coverage of Soviet Union data.

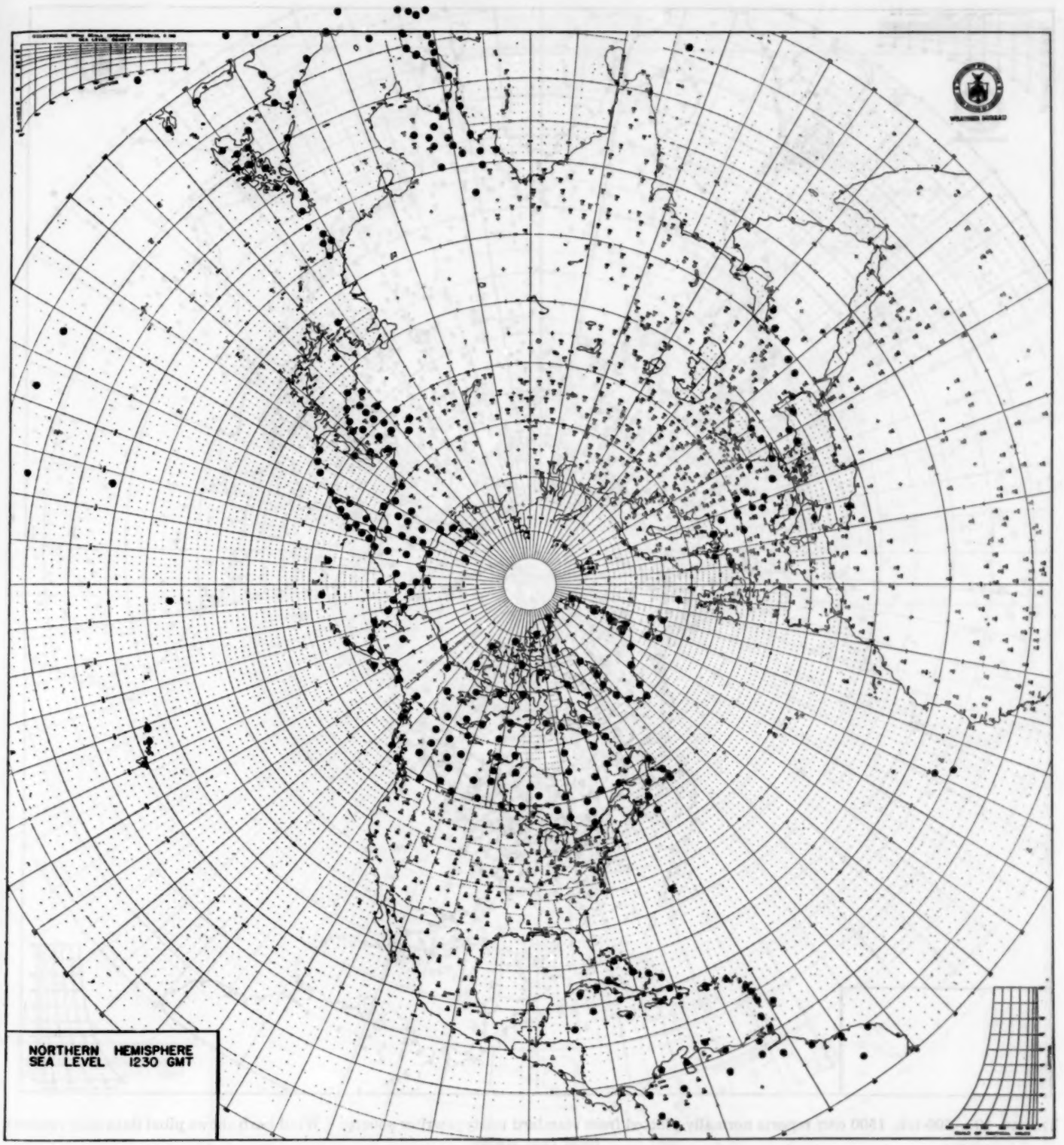

FIGURE 9.—Sea level 1230 GMT reports normally plotted from standard teletypewriter source.

The intense coverage of the Soviet Union afforded by this intercept teletypewriter source is shown in figure 8. While the fact that this coverage is for only one day chosen at random may detract from its representativeness on an average basis, it does show that on this day 1141 reports for the Soviet Union were available through this one source. Because of the physical limitations of the base maps used, about 300 of these stations are normally plotted on the current Northern Hemisphere sea level maps.

Figures 9 and 10 show the areas that must be filled-in from standard teletypewriter source as received at various weather centrals in the United States. As general insurance to obtain the most complete coverage possible for

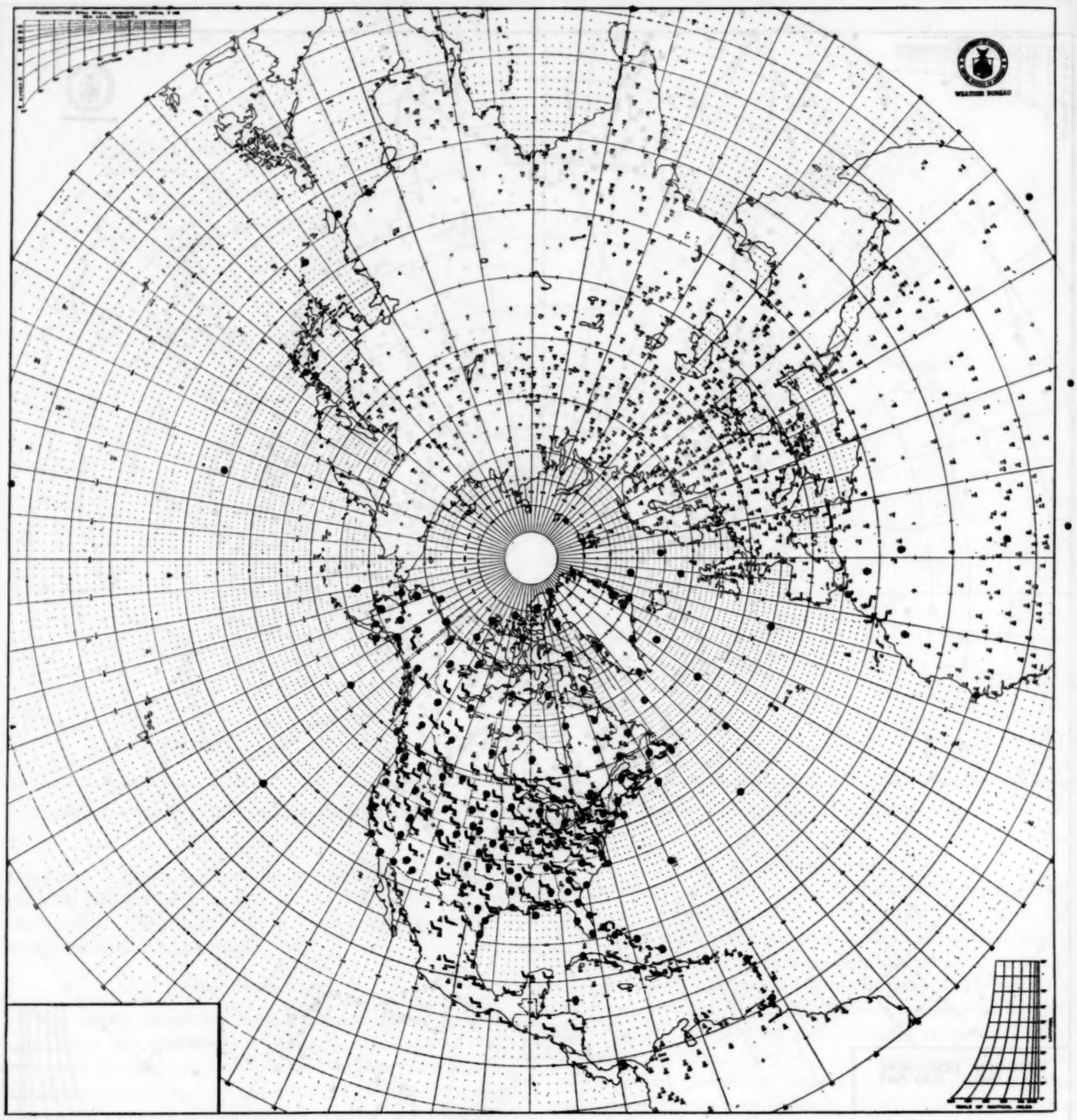

FIGURE 10.—500-mb. 1500 GMT reports normally plotted from standard teletypewriter source. Wind barb shows pibal data only received from that station.

the entire hemisphere, teletypewriter material as received by the Extended Forecast Section of the Weather Bureau and the National Weather Analysis Center in Washington, D. C., is forwarded on a regular basis to the NWRC for use on the current project. Use of the teletypewriter source for reports in the United States and Canada was explained above.

Because of the late receipt of some of the weather logs of ships, about half of the 200 to 250 ship reports plotted, and 450 to 500 tabulated for each day are taken from the teletypewriter source.

Many of the individual units in these sources overlap as to area covered, and the duplications of reports in the teletypewriter sources are so numerous that they defy accurate

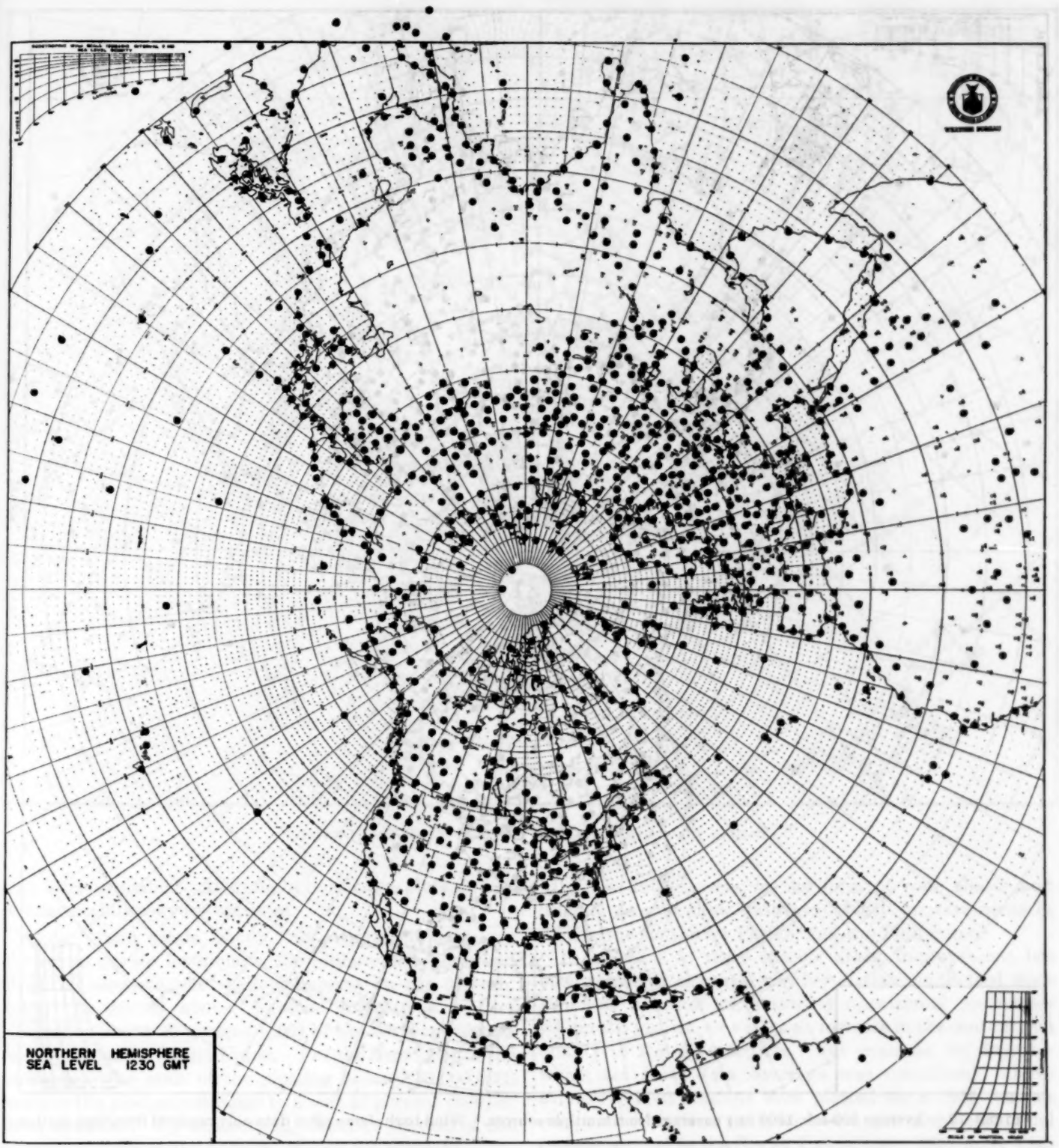

FIGURE 11.—Average sea level 1230 GMT coverage from multiple sources. (Ships-at-sea reports not shown.)

enumeration. The stations indicated as being included in a particular source on the maps are the ones that can normally be expected to appear in that source, and this is classed as the "primary" source for these stations; but because of a delayed shipment of records, the garbling or absence of a teletypewriter sequence, or a break in a series of publications, it is often necessary, and always desirable, to use another source although it may be a less reliable one. Under the 6-month lag, month-per-month production commitment of the current project, unlimited time is

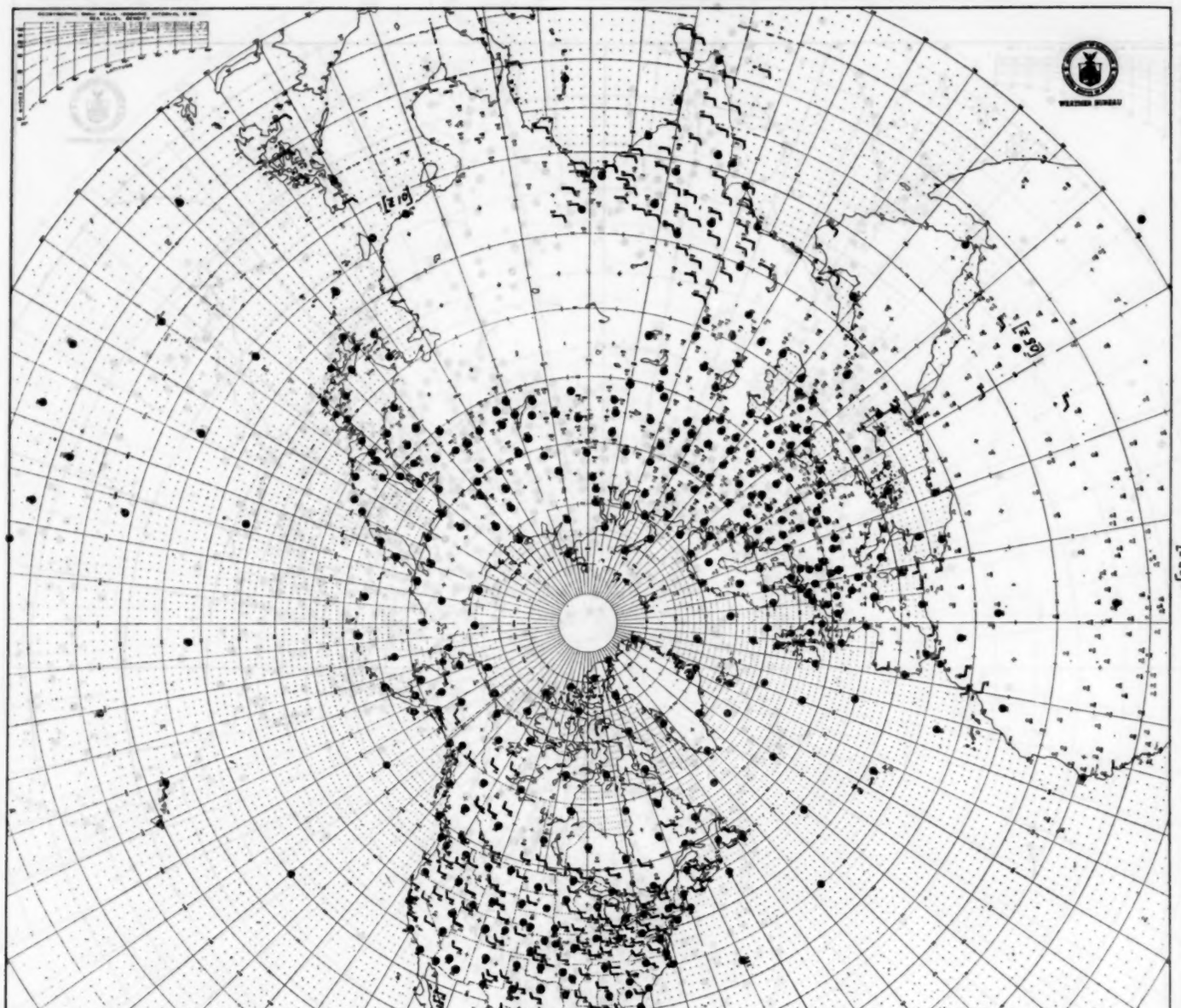

FIGURE 12.—Average 500-mb. 1500 GMT coverage from multiple sources. Wind barb shows pibal data only received from that station.

not available for data collection and editing. When data are missing from a primary source, plotters are obligated to plot the missing stations from another source if possible, but just how long to search for the missing data until the time spent outweighs the value of the data found is a continual problem.

COVERAGE FROM MULTIPLE SOURCES

Figures 11 and 12 are composite maps of the average coverage of reports plotted on the current Northern Hemisphere Series. From 200 to 250 reports from ships at sea are not indicated on the sea level map, and reports from reconnaissance aircraft normally plotted on the 500-mb. map are shown in figure 13. During the earlier years of the current series these in-flight reports generally were not plotted, but because of increased accuracy in more recent years they are found to be a definite aid in defining both the height and temperature field at 500 mb. Dropsonde data from in-flight reports supplement the sea level

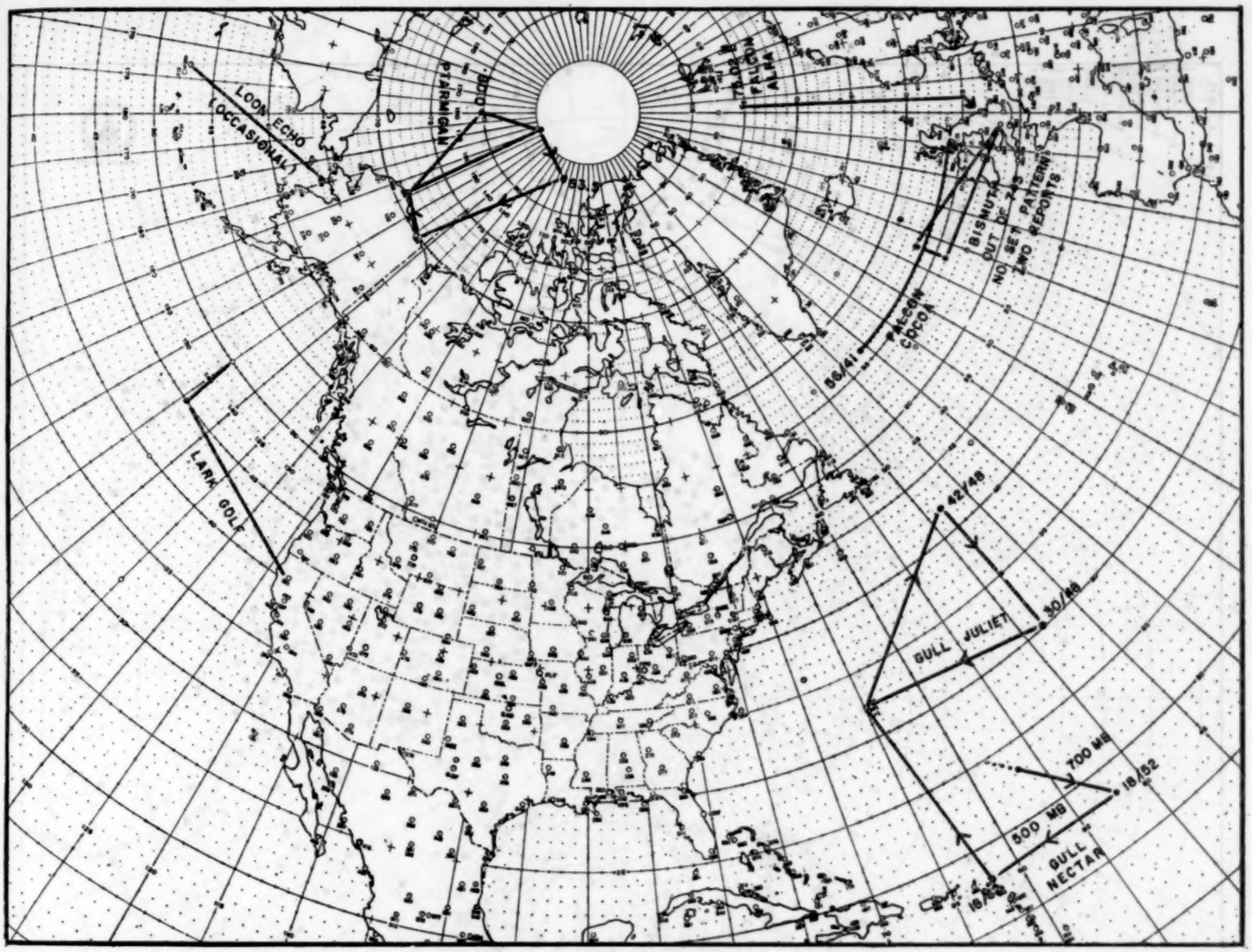

FIGURE 13.—500-mb. 1500 GMT flight reports normally plotted.

map when available. All in-flight reports are plotted from standard teletypewriter material.

As for grand totals, about 1100 reports normally are plotted on the sea level maps; 330 radiosonde reports and about 60 separate pilot balloon reports on the 500-mb. maps. As stated above, physical limitations restrict plotting to about 26 percent (300) of the sea level reports received from the Soviet Union. For the remainder of the hemisphere the scale of the plotting base (1:30,000,000) restricts the plottable stations to about 40 percent (800) of those available. By comparison, about 99 percent of the reports received at the 500-mb. surface are plottable.

The most marked area of a lack of reports on both the sea level and the 500-mb. maps is the general area of continental China and the plateau of south-central Asia. It is hoped that observational programs during the International Geophysical Year will be a large step forward in new data availability [3]. That this field is not dormant can be shown by comparing the "Data Density" map for January 17, 1953 [4] (not shown), with figures 3 and 12. Multiple data sources in the form of code sheets and original records show data availability improvements in Africa, the southwest Pacific, and the Philippines.

In addition to these specific areas, improvement has been shown in the total number of stations plotted since 1953—as a result of improved operational techniques within the project, as well as an increase in the content and quality of the data sources. For example, on days for which sea level data coverage was considered "above average", 1160 stations were plotted on a 1955 map as compared to 1004 in 1953, with over 100 of the additional reports plotted in the Soviet Union; since 1953 more than 40 additional 1500 GMT radiosonde reports from the Soviet Union are now plotted on the 500-mb. maps. It is apparent that some of this latter increase must be attributed to an accelerated upper air program in the Soviet Union during the last few years.

Failure of transmission of meteorological data by electrical means has long been a plague to the operational plotter and analyst. That this can be quite serious, and at the same time can be overcome by use of multiple data

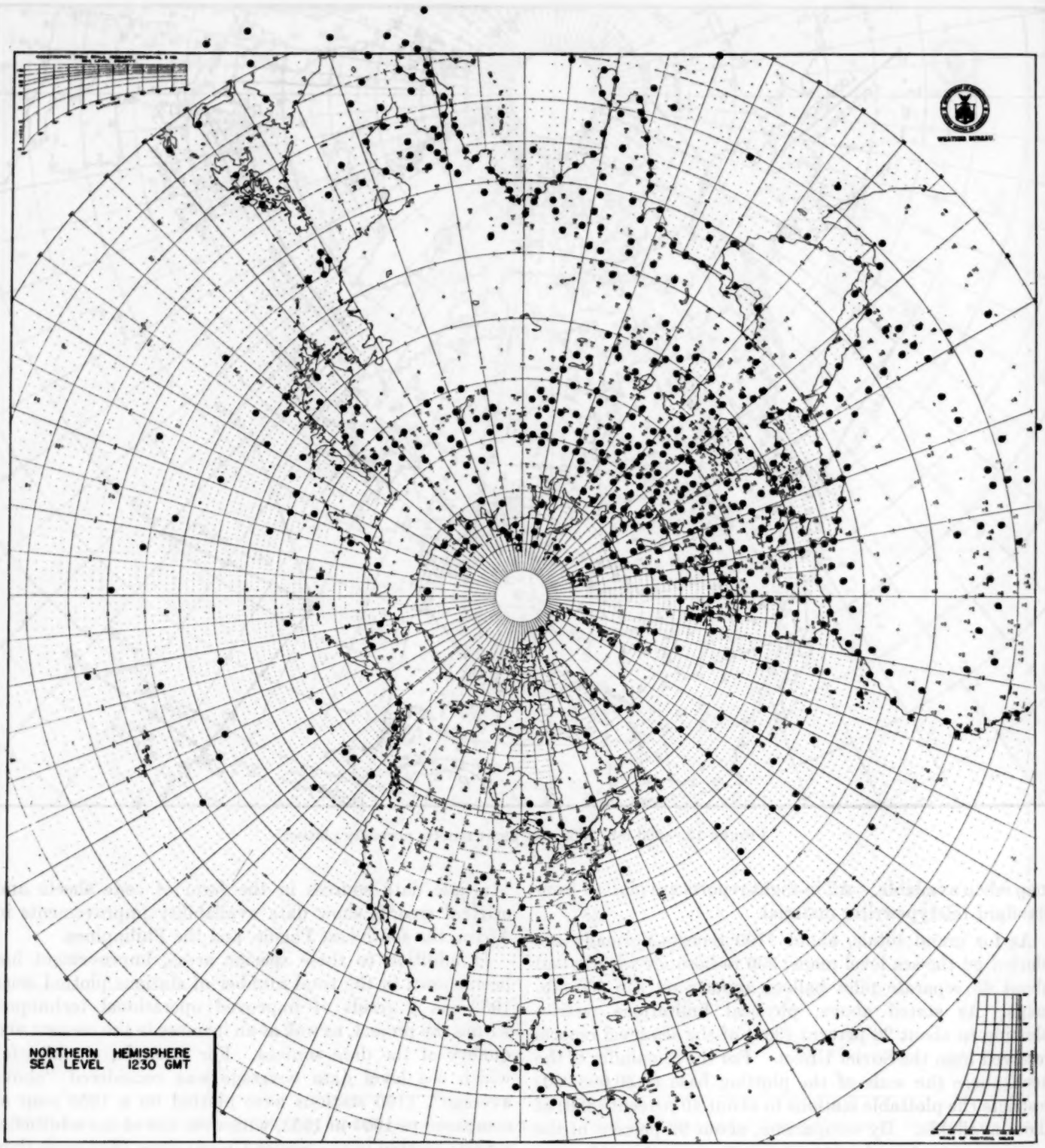

FIGURE 14.—Additional sea level 1230 GMT reports plotted from multiple sources on day of poor standard teletypewriter receipt.

sources with an extended period for data collection, is shown in figures 14 and 15. These maps show actual additional reports plotted from sources other than standard teletypewriter. The original operational map (Extended Forecast Section, November 17, 1955) was analyzed with over 600 1230 GMT reports less than the number available to the Northern Hemisphere current project analyst; the 500-mb. map (NWAC August 2, 1955) was analyzed operationally without the benefit of the 140 additional radiosonde reports and 32 pilot balloon reports shown in figure 15. Admittedly, these examples are selected exceptions and occur rather infrequently. How-

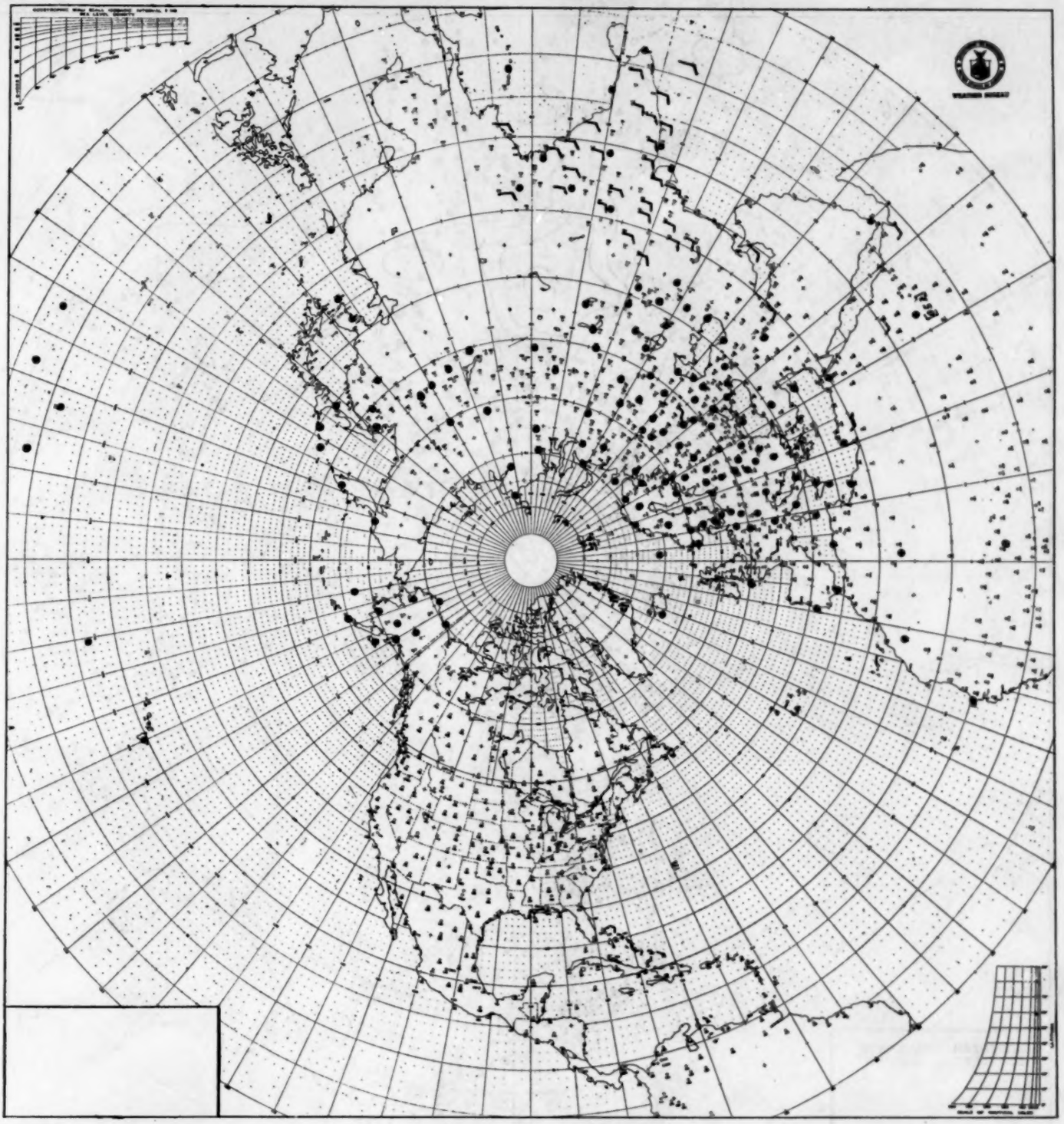

FIGURE 15.—Additional 500-mb. 1500 GMT reports plotted from multiple sources on day of poor standard teletypewriter receipt. Wind barb shows pibal data only received from that station.

ever, extended periods of aurora or other electrical interference can cause this incomplete receipt of data by standard teletypewriter to continue intermittently for some time.

EFFECT OF ADDITIONAL DATA ON ANALYSES

In an effort to show the effect of these additional data upon analysis, two operational maps were chosen at random, with the additional data available some months later from multiple sources spotted on maps shown in figures 16 and 17. These are examples chosen at random, but it is believed they show too marked a difference in data receipt. While *averages* have been determined as 300–325 *additional* reports on a current Northern Hemisphere sea level map, and about 35 *additional* reports on a

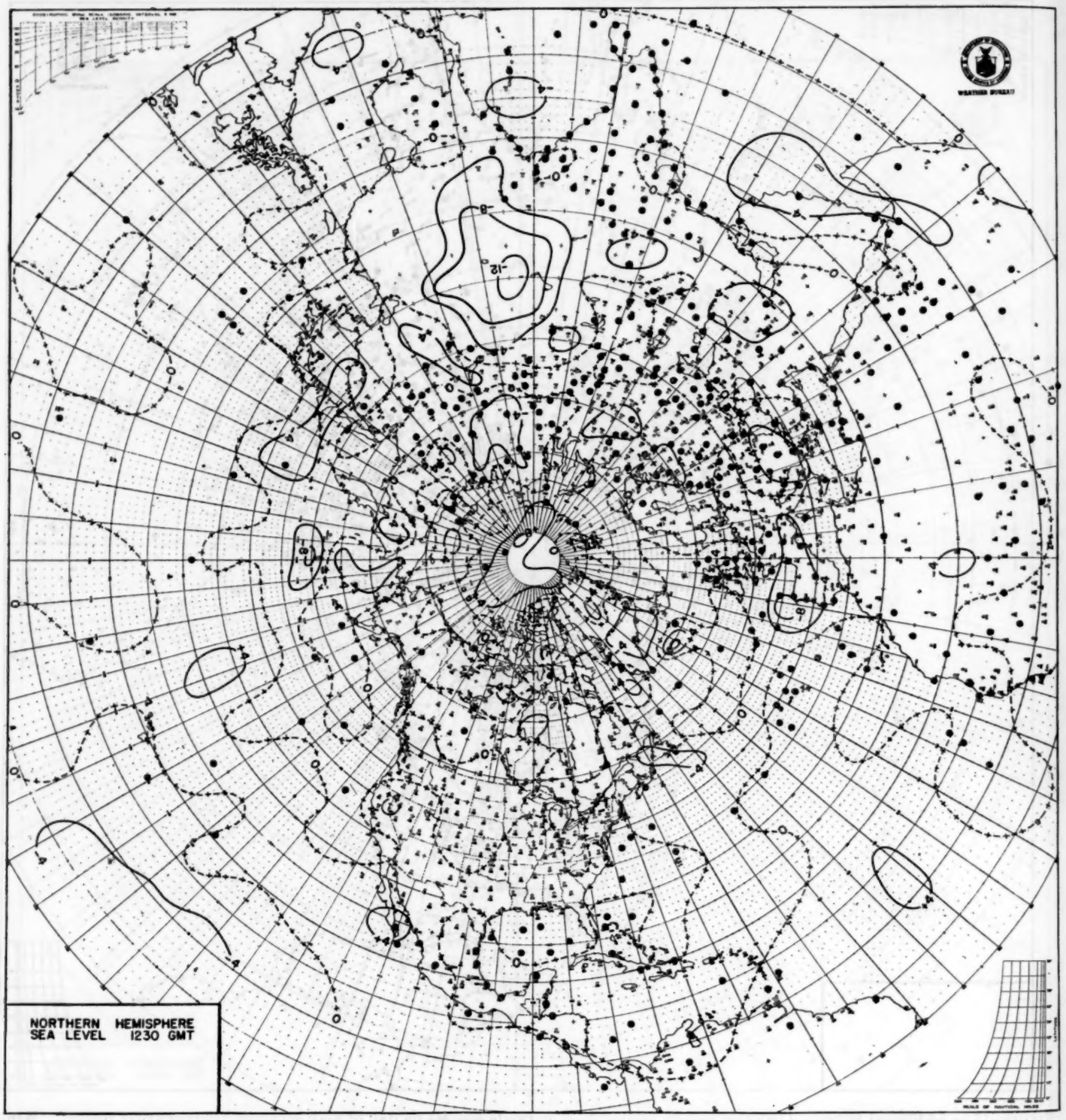

FIGURE 16.—Sea level 1230 GMT reports additional to those received in time for regular operational analysis, and isolines of significant difference between operational and Northern Hemisphere analyses. Significant difference: 0.66 mb.; interval: 4 "significants".

500-mb. map, these spotted maps show 419 and 114 additional reports respectively.

Values from the contours and isobars of the analyzed maps were read at grid intersections and a "difference" map was drawn. Since it is realized that two analyses of the same data by different analysts would not be exactly the same, the analysis difference over the United States, where little or no data were added, was taken as a basis of significance. Excesses of this difference (two-thirds of a millibar for the sea level analysis, and 30 ft. for the 500-mb. analysis) were considered significant and lines connecting values of equal significant differences (in increments of 4 "significants") in analyses are shown in figures 16 and 17.

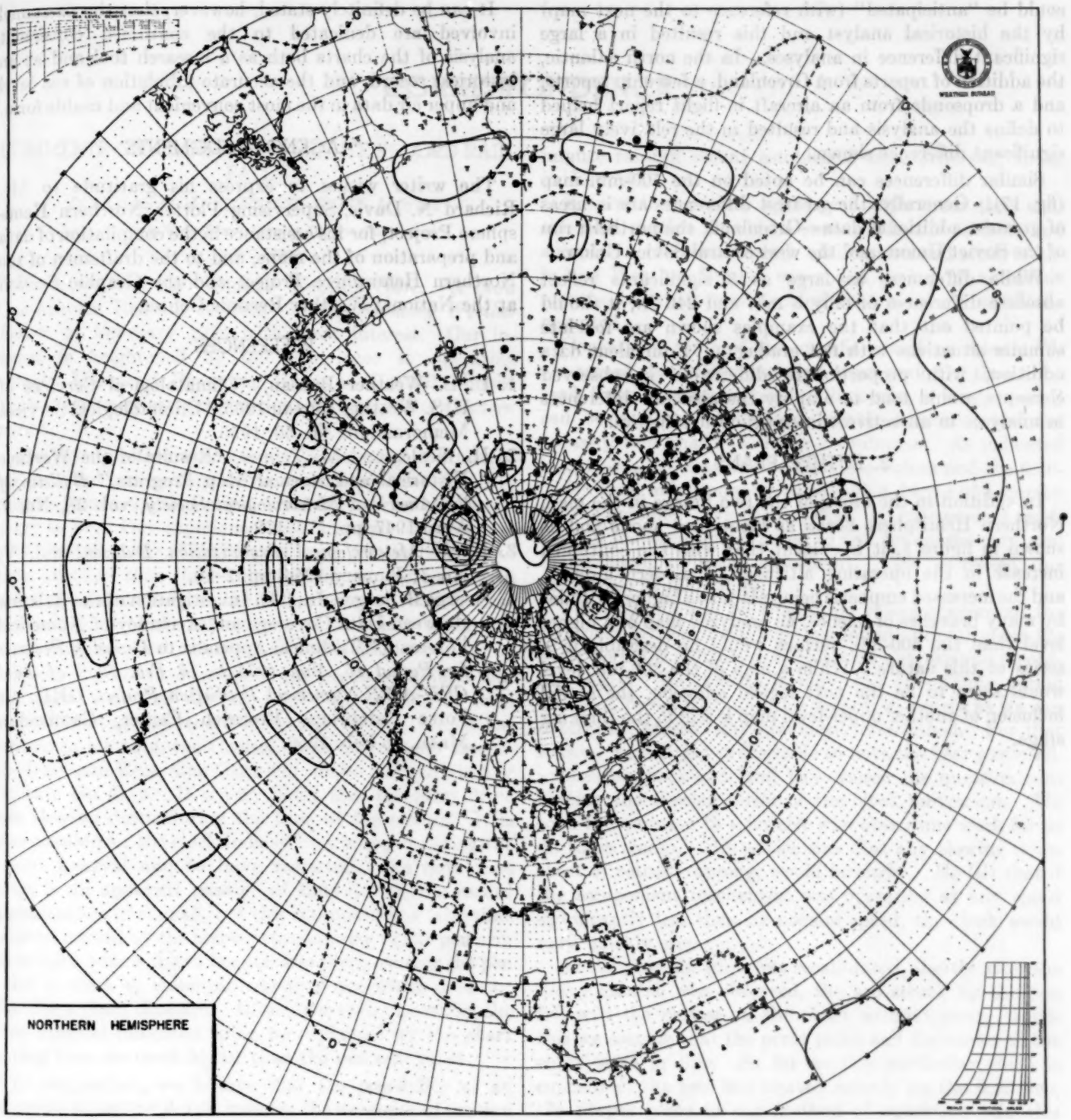

FIGURE 17.—500-mb. 1500 GMT reports additional to those received in time for regular operational analysis, and isolines of significant difference between operational and Northern Hemisphere analyses. Significant difference: 30 ft.; interval: 4 "significants". Dot and wind barb together indicate both height and wind data available for that station.

Not all of this difference is due to additional available data. Undoubtedly, every forecaster or analyst at some time has said to himself, "If I could only see the next map!"—and that is exactly what the Northern Hemisphere Series analyst does see—the next map. This advantage of establishing continuity by adjusting the present analysis in view of the map before and the map after, resulted in significant analysis differences most noticeably in the China area where no data were available on either set of maps, but where the analyst of the historical series had the advantage of "hindcasting."

On the sea level analysis (fig. 16), a large pressure fall in the vicinity of the Aleutians looked unreasonable to the operational analyst, but the subsequent rapid development

could be "anticipated" (with reference to the next map) by the historical analyst and this resulted in a large significant difference in analyses. In the north Atlantic, the addition of reports from Greenland, a few ship reports, and a dropsonde from an aircraft in-flight report helped to define the analysis and resulted in the relatively large significant difference shown.

Similar differences can be noted on the 500-mb. map (fig. 17). Generally, the greatest differences are in areas of greatest additional data—Greenland, the northern rim of the Soviet Union, and the west central Soviet Union.

While differences as large as 8 significants reflect absolute differences of only 5 mb. and 240 ft., it should be pointed out that the examples shown are for late summer situations with flat gradients. Equivalent data addition, with proportionate differences in observed elements, would tend to amplify the absolute differences in analyses in an active winter synoptic situation.

3. FUTURE PLANS

In addition to the filling of the two breaks in the main Northern Hemisphere Series as mentioned above and as shown in figure 1, it is evident that with the continued increase in the operating altitudes of modern aircraft, and the increased emphasis being placed on higher altitudes by many branches of science, an analyzed map of a higher level than the 500-mb. surface would be desirable in a series of this nature. While a map of the 300-mb. level would seem to be the next logical addition, the actual inclusion of another upper-level map is still in the thinking stage.

It can be definitely stated, however, that the personnel involved are dedicated to the continued consistent analysis of the charts both as a research tool and as an historical record, and the accurate tabulation of sea level and upper air data in the most convenient and usable form.

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Mr. Richard N. Davis, Supervising Plotter, Northern Hemisphere Project, for his assistance in the compilation of data and preparation of the maps, and to the draftsmen of the Northern Hemisphere Project and the Graphic Section at the National Weather Records Center.

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2. H. Wexler and M. Tepper, "Results of the Wartime Historical and Normal Map Program," *Bulletin of the American Meteorological Society*, vol. 28, No. 4, April 1947, pp. 175–178.
3. *World Meteorological Organization Bulletin*, vol. V, No. 1, January 1956, pp. 2–10.
4. George B. Seager, Jr., "An Investigation of the Relation Between Data Coverage and Accuracy of Numerical Forecasts," Technical Appendix to *Report of Progress for Period 15 Aug. 1955 to 15 Feb. 1956 of Joint GRD-AWS Numerical Prediction Project*, GRD, Air Force Cambridge Research Center, Cambridge, Mass., 15 Feb. 1956.

CORRESPONDENCE

COMMENTS ON "A NEW ONE-MINUTE RECORD RAINFALL"

DOUGLAS M. A. JONES AND FLOYD A. HUFF

State Water Survey Division, Urbana, Ill.

June 5, 1956

We have read Mr. Elford's Weather Note, "A New One-Minute Rainfall Record," in the *Monthly Weather Review* of February 1956 with great interest. Our interest is heightened by our experience in operating seventy Universal Recording Gages in Central Illinois. We wish to raise certain questions with regard to the new record.

The first question would be the practicality of attempting to read an accumulative rainfall amount for 0.10 minute from a 24-hour chart which we assume the record chart to be. Our experience with an analysis procedure very similar to Mr. Elford's has been that increments of time smaller than four minutes cannot be read with accuracy, particularly at the higher rates of rainfall since determination of the intersection of two lines which are nearly parallel is subject to considerable ambiguity.

Another point in question is the great possibility that the gage clock was running at a reduced rate or even stopped during the record interval. As Mr. Elford has written in his note, the Chelsea clock movements used in the Universal Recording Gage will run on a single winding for only ten days. It is very likely that the chart drive was slowing down during the time of the record. It is also possible for the clock to have been stopped during the record interval and to have restarted. We note that there is an apparent passage of time during the record accumulation of rainfall, but this is sometimes a false time interval caused by the inaccurate centering of the pen arm from the 4.5-inch line to the pen arm pivot causing the pen point to trace an instantaneous time line which does not describe a chart time arc. In the case under question, the time interval indicated could be explained by the chart having been centered higher than the pen arm pivot.

In summation, we believe that the possibility of an incorrect recording should indicate the necessity of caution in accepting this gage recording as a new record in excessive one-minute rainfall. Mr. Elford's comments will be appreciated.

REPLY

C. ROBERT ELFORD

Weather Bureau Office, Des Moines, Iowa

June 29, 1956

We appreciate the letter of June 5 from Messrs. Jones and Huff, raising some questions concerning the one-minute rainfall record established near Jefferson, Iowa, in July 1955.

We are in complete agreement with them that considerable caution should be exercised in the analysis and acceptance of such a record. Discussion and study within the Weather Bureau covered a period of about six months before it was decided that a record would be accepted.

Concerning some of the specific questions raised: We are agreed that 0.10 minute is a short period of time to be read from a 24-hour chart. Obviously, a longer period can be read with somewhat greater accuracy, and the actual period finally used was 1.4 minutes. As indicated in our note, we read the 0.10-minute values and the 0.10-inch values independently to as high a degree of accuracy as was possible. We then plotted the independent readings on the same graph paper to test for consistency, and found them in good agreement. This increased our confidence in the values.

There might well be a question raised concerning the propriety of recognizing any one-minute rainfall since the short period is difficult to evaluate on any existing recording charts. Be that as it may, the one-minute period has been recognized, and this record, as nearly as we can determine, exceeds any previously established. For that reason, we thought it desirable to note the heavy rainfall.

Messrs. Jones and Huff have raised the question concerning the slowing down of the clock movement. We took the question to a jeweler who does some work for us on these clocks. His advice was that any slowing down short of actual stopping, would be slight. He felt that if the escapement mechanism was operating at any speed significantly less than its normal speed, the clock would very quickly stop.

At the time the gage was recalibrated, shortly after the heavy rainfall was observed, the arc struck by the pen followed the curves on the chart without error. From this we assume that the pivot point and the center of the chart were in line. So far as this particular chart is concerned, the pen line started exactly on the 0.50 line, the proper place in our method of operation. In this respect it agreed with the charts that were on previous to and following this chart, and also agreed with the calibration chart. As a matter of fact this chart very nearly fills the drum, and since the clip hooks over the drop of the chart and the drum, it would be impossible for the chart to be off more than a small fraction of an inch.

Each of these items was carefully considered before the record was accepted, and it is believed that a new record one-minute rainfall can be accepted with the same degree of confidence that has been attached to previous one-minute records.

THE WEATHER AND CIRCULATION OF JUNE 1956[1]

Another Hot June in Central United States

RAYMOND A. GREEN

Extended Forecast Section, U. S. Weather Bureau, Washington, D. C.

1. INTRODUCTION

June 1956 was characterized by abnormal warmth over central United States. This represented a marked reversal from last year but followed the trend of June temperatures for the three previous years, when heat waves were produced over central and eastern United States [1]. This time the heat wave area was centered farther west than in Junes from 1952 to 1954, and above normal temperatures dominated the country from the Southwest through the Great Plains to the Great Lakes

[1] See Charts I–XVII following p. 252 for analyzed climatological data for the month.

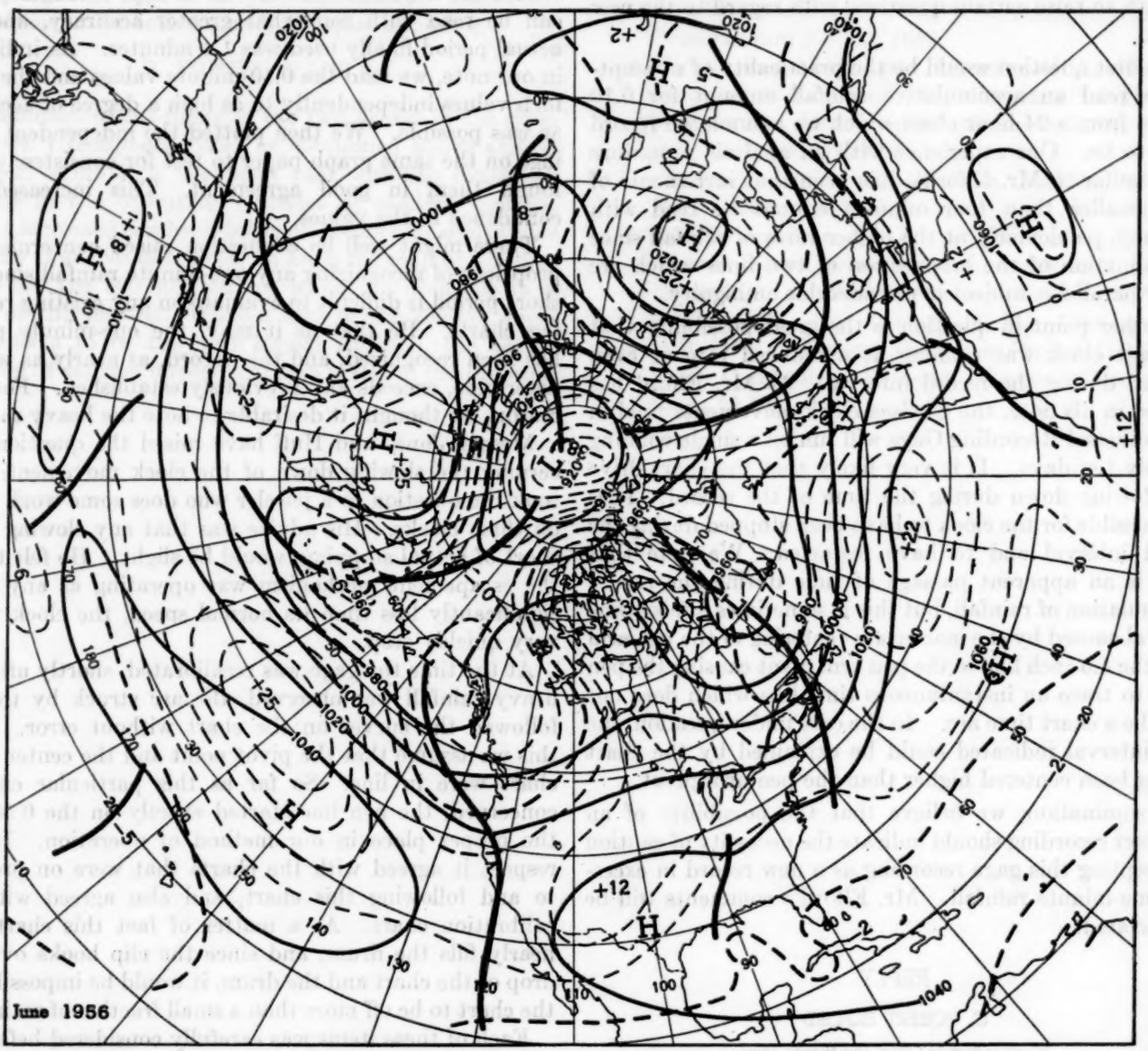

FIGURE 1.—Monthly mean 700-mb. height contours and departures from normal (both in tens of feet) for June 1956. Note large height anomaly center (−350 ft.) near the North Pole and centers of blocking activity in northeastern Canada and Siberia and northern Russia. The subtropical anticyclone belt appears north of its usual position and stronger than normal from mid-Pacific through United States to western Europe.

(See Chart I-B). Anticyclonic circulation features characteristic of hot weather were very much in evidence this month and will be discussed in the following section on general circulation.

2. GENERAL CIRCULATION

Mean hemispheric circulation for June 1956 (fig. 1) exhibited several interesting features including: (1) An abnormally deep Low in the Arctic Basin. (2) A surrounding belt of high pressure containing three areas of maximum blocking activity, in northern Canada, northeastern Siberia, and northern Russia. (3) A strong subtropical high pressure belt, lying unusually far to the North, from mid-Pacific through the United States and central Atlantic. Added aspects of the last feature included a fast westerly 700-mb. jet stream displaced north of its normal location (figs. 2, 3), and unseasonably strong development of tropical easterlies (fig. 3).

Fifteen-day mean maps for the month (fig. 4A and B) show how 700-mb. circulation features shifted from the first to the latter half-month. Significant transitions included filling of the west coast trough, collapse of the subtropical ridge over north central United States, and eastward motion of the east coast trough into the Atlantic. Also noteworthy were large 700-mb. height changes between the two halves of the month over Baffin Island (fig. 5), suggestive of a return toward the April blocking picture described by Dunn [2].

In describing the April-May 1956 circulation reversal, Klein [3] emphasized the poleward shift of several circulation features in May. The shift continued through June over the United States, as shown by figure 6, which gives successive mean monthly positions of the 700-mb. jet stream. The northward march was especially pronounced over western United States, where a well-marked zone of maximum westerlies replaced May's poorly defined wind field. Normally only a slight northward shift occurs from April to May.

Northward displacement of the subtropical anticyclone belt has been suggested by Namias and Dunn [4] as conducive to formation of tropical disturbances early in the season. A good example of northward displacement is seen in the 700-mb. height departure from normal field for June 1–15 (fig. 4A). Its suggested relationship to tropical activity can perhaps be further substantiated by the appearance of the season's first tropical storm in the Gulf of Mexico on June 13. Tropical storms are infrequent over the Gulf in June, this being only the second observed since 1946. The other was hurricane Alice in

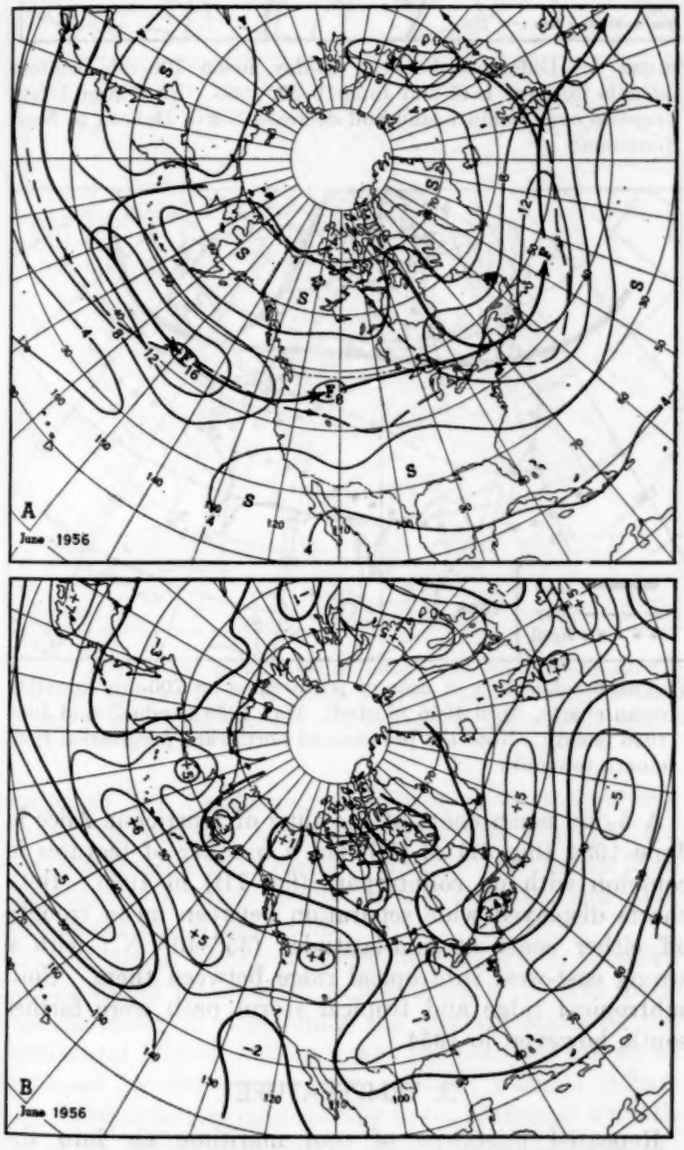

FIGURE 2.—(A) Mean 700-mb. isotachs and (B) departure from normal wind speed (both in meters per second) for June 1956. Solid arrows in (A) indicate axis of the mean jet stream at the 700-mb. level, which was north of its normal June position (dashed) in most sectors.

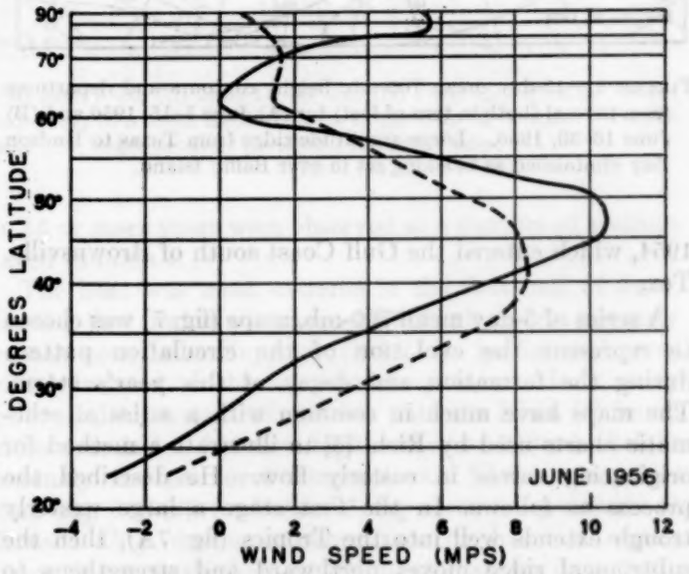

FIGURE 3.—Monthly mean zonal wind speed profiles for the Western Hemisphere at 700-mb. for June 1956 and June normal (dashed). Note northward displacement and intensification of the westerly maximum and stronger than normal subtropical easterlies (negative values).

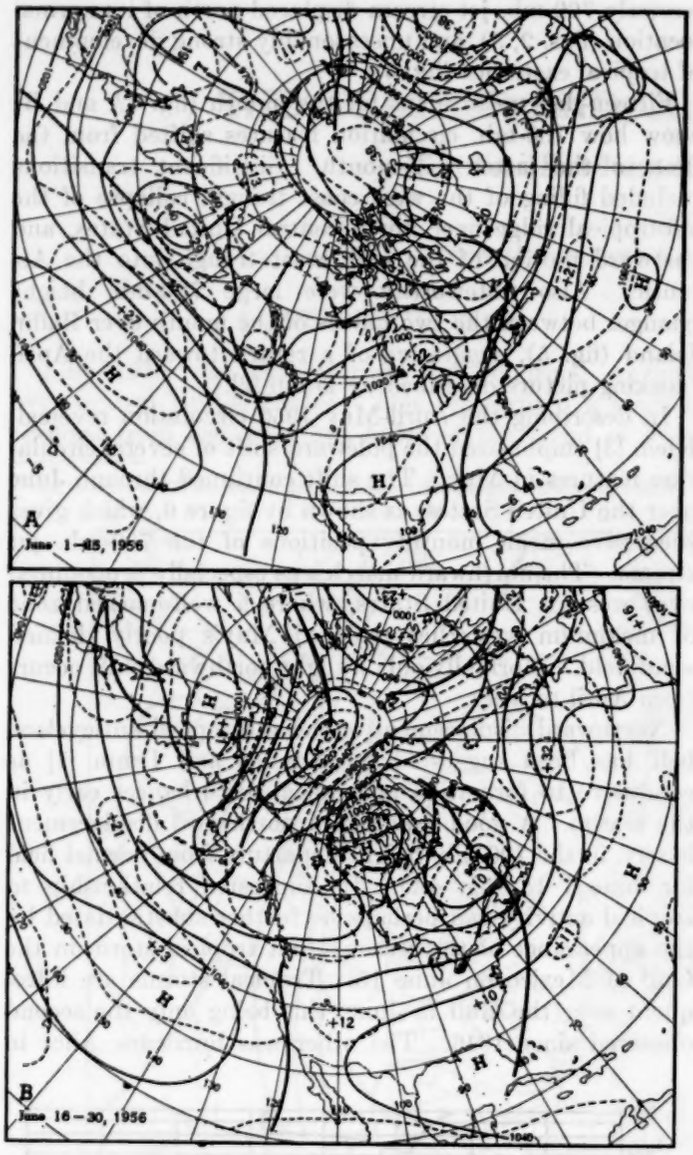

FIGURE 4.—15-day mean 700-mb. height contours and departures from normal (both in tens of feet) for (A) June 1–15, 1956 and (B) June 16–30, 1956. Large-amplitude ridge from Texas to Hudson Bay diminished as blocking set in over Baffin Island.

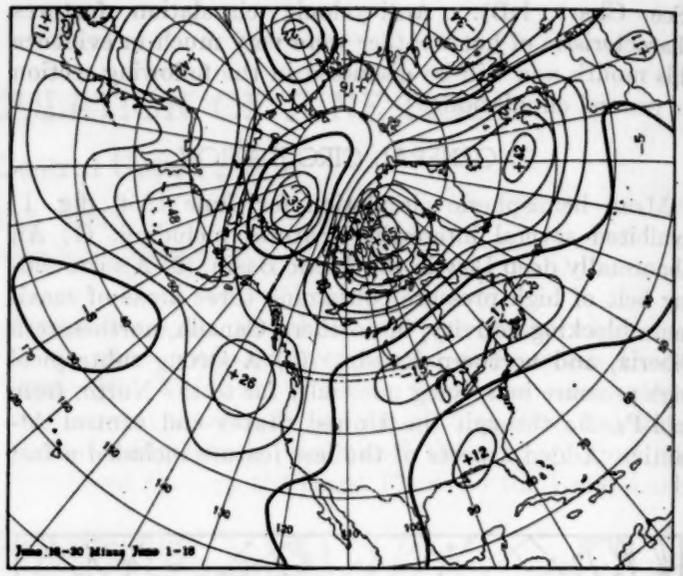

FIGURE 5.—Difference between 15-day mean 700-mb. contour heights for June 1–15 and June 16–30, 1956. Note large height increase over Baffin Island and decrease North Dakota to Newfoundland.

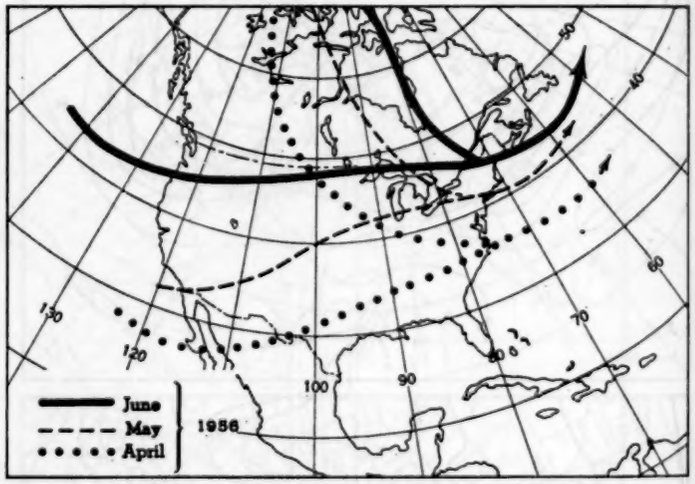

FIGURE 6.—Location of axes of jet streams on 700-mb. monthly mean charts, April 1956 (dotted), May 1956 (dashed) and June 1956 (solid). Note the pronounced northward progression from month to month.

1954, which entered the Gulf Coast south of Brownsville, Tex.

A series of 5-day mean 700-mb. maps (fig. 7) was chosen to represent the evolution of the circulation pattern during the formation and decay of this year's storm. The maps have much in common with a series of schematic charts used by Riehl [5] to illustrate a method for originating waves in easterly flow. He described the process as follows: In the first stage a large westerly trough extends well into the Tropics (fig. 7A), then the subtropical ridge moves northward and strengthens to cause wave fracture (fig. 7B). Riehl stated that the waves ordinarily weaken after fracture, with an exception when a cyclonic circulation forms in the easterly trough. Apparently this storm was an example of that exception.

A 5-day mean chart at the time of Hurricane Alice in June 1954 (fig. 6D of [1]) had a number of features in common with its counterpart (fig. 7B) in 1956. Both charts displayed wide separation between mean troughs off either coast at mid-latitudes (35°–40° N.) with a strong east-west subtropical ridge between them. Both subtropical ridge and tropical storm path were farther south, however, in 1954.

3. TEMPERATURE

Repeated injections of cool maritime air into the Pacific Northwest followed the increased westerly flow which accompanied changes in the circulation pattern from May to June. Seven Pacific fronts entered the country during the month of June, five of them extending

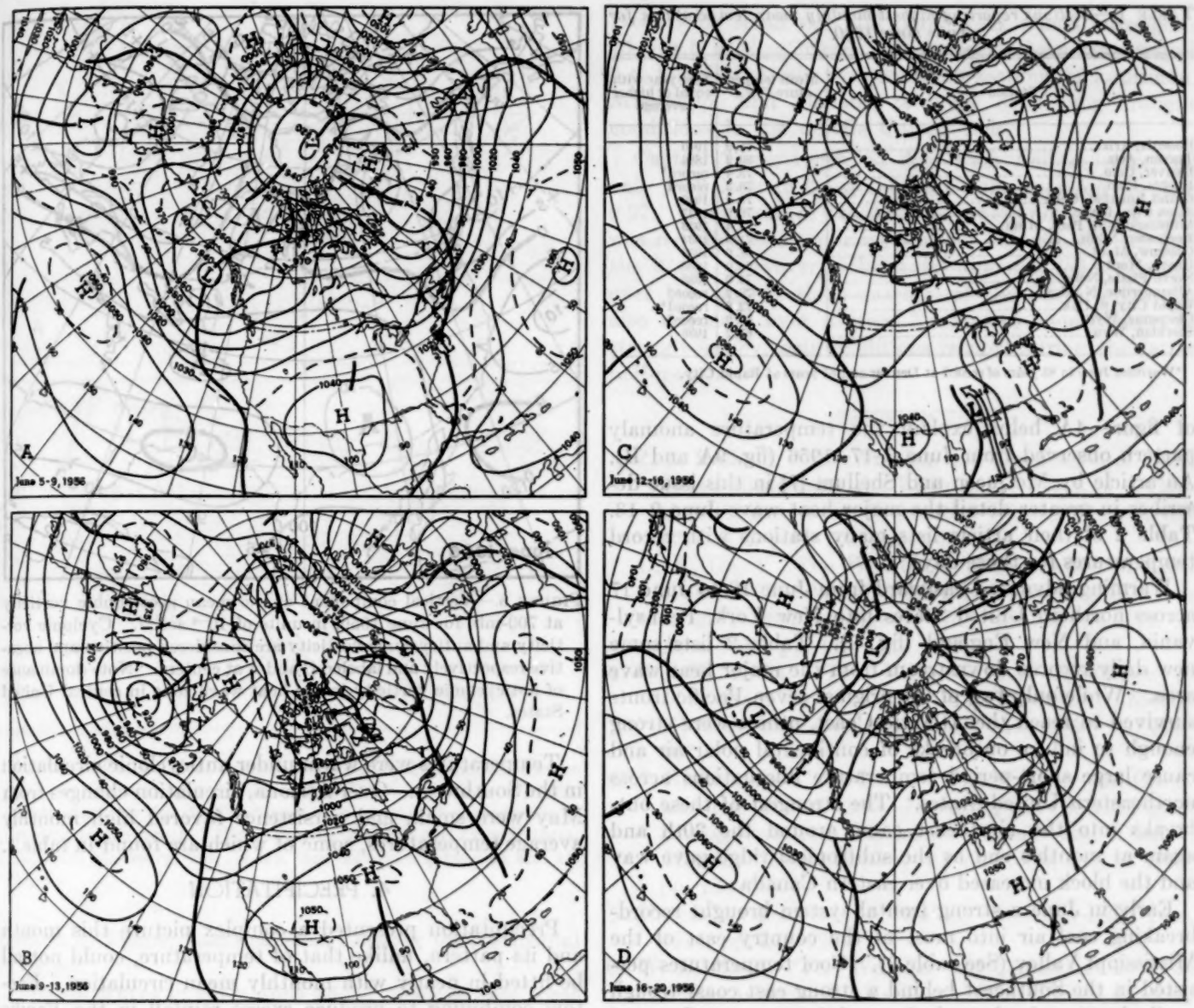

FIGURE 7.—Five-day mean 700-mb. height contours for (A) June 5–9, (B) June 9–13, (C) June 12–16, and (D) June 16–20, 1956. These charts show evolution of 5-day mean circulation during formation and decay of a small tropical storm in the Gulf of Mexico. Trajectory of this storm from the 12th to the 14th, given by the open arrow of (C), approximately paralleled the mean flow.

southward into California. Resulting cool temperatures (Chart I-B) marked a reversal from the May pattern over Washington and Oregon. An extreme change from much above to much below normal temperatures took place in eastern Washington.

Pacific air in strong westerly flow over the northern Rockies would be expected to lose much of its cool maritime character in descending the eastern slopes of the Continental Divide, and such was the case this month as evidenced by the temperature anomaly pattern (Chart I-B). Other factors contributing to the abnormal warmth east of the Divide were above normal height values (fig. 1) and anticyclonic relative vorticity (fig. 8) on the 700-mb. monthly mean map. Highest average June temperatures in 15 or more years were observed at a number of stations listed in table 1.

The heat was most extreme in the first half of June. During that period a pronounced 700-mb. height anomaly center near Lake Superior (+220 ft. in fig. 4A) was closely related to the temperature pattern. In a study of typical heat wave circulation patterns Klein [6] found close association between high values of 700-mb. height anomaly and sea level temperature. Klein's composite map (fig. 5 of [6]) for hottest 5-day mean temperatures at Kansas City during summer months bears a strong resemblance to the half-month mean map for June 1–15, 1956 (fig. 4A). Shifting most features of the composite map slightly northwestward into juxtaposition with those

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TABLE 1.—*Stations reporting highest monthly mean temperatures for June since 1940*

Station	Mean temperature (° F.)	Last year with equal or higher average
Phoenix, Ariz.	86.9	1940
Tucson, Ariz.	86.2	1886
Denver, Colo.	73.4	record*
Pueblo, Colo.	76.3	record
Grand Junction, Colo.	75.4	1940
Sioux City, Iowa	76.9	1933
Minneapolis-St. Paul, Minn.	73.4	1933
Rochester, Minn.	71.9	1934
Glasgow, Mont.	67.6	1936
Havre, Mont.	66.0	1936
North Platte, Nebr.	74.0	1933
Albuquerque, N. Mex.	78.9	record
Rapid City, S. Dak.	72.8	record*
Cheyenne, Wyo.	67.2	record
Sheridan, Wyo.	67.2	1936

*Warmest June in 85 years of record at Denver and 65 years at Rapid City.

of figure 4A helps explain the temperature anomaly pattern observed from June 3–17, 1956 (fig. 9A and B). An article by McQueen and Shellum [7] in this issue describes in greater detail the major heat wave June 9–13. Table 2 of their article lists many stations with record temperatures for those days.

Warming advanced eastward from June 10 to June 17 across northern United States into New York, Pennsylvania, and New England (fig. 9). Table 2 lists some new daily records downstream from the major heat wave area. While only two of the original seven Pacific fronts survived to reach the Atlantic Coast, others were strong enough to induce outbreaks of continental polar air and cause large short-period temperature fluctuations across northeastern United States. The strongest of these outbreaks into the Northeast came around the 20th and again at month's end as the subtropical ridge gave way and the block increased over eastern Canada.

Early in June a strong frontal system brought record-breaking cool air into most of the country east of the Mississippi Valley (See table 3). Cool temperatures persisted in the Southeast behind a strong east coast trough until the trough showed signs of fracture on June 10 (fig. 9A). Thereafter, cooling shifted westward with the easterly portion of the trough. Cloudiness and precipitation in the trough and its associated tropical storm persisted for several days. Temperatures over all the Gulf States as well as Arkansas and parts of Oklahoma, Missouri, and Tennessee were affected by this relatively weak storm (fig. 9B).

TABLE 2.—*Daily record high temperatures occurring in the East after the major heat wave in the Midwest, June 9–13, 1956.*

Date	Place	Temperature (°F.)
14	Newark, N. J.	99
14	Trenton, N. J.	96
14	Syracuse, N. Y.	92
14	Reading, Pa.	96
14	Scranton, Pa.	92
14	Providence, R. I.	92
15	Syracuse, N. Y.	92
15	Richmond, Va.	96
16	Nantucket, Mass.	87

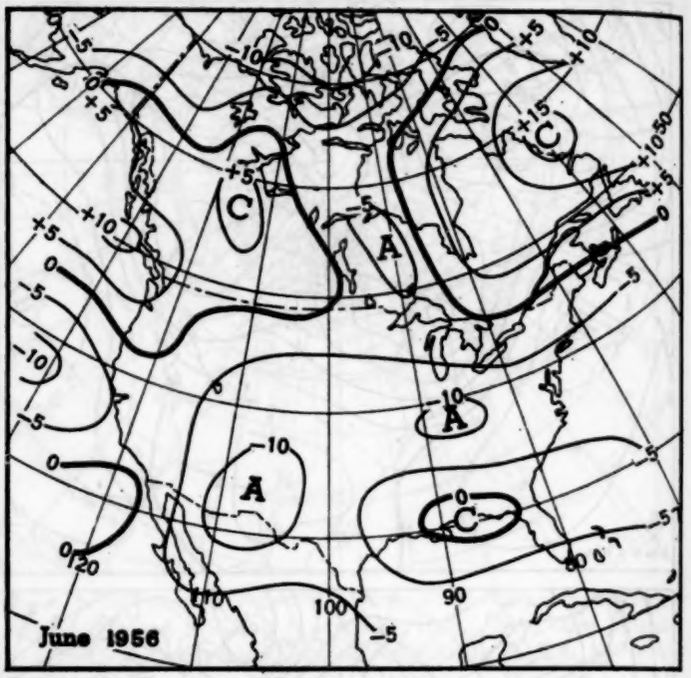

FIGURE 8.—Vertical component of the mean geostrophic vorticity at 700-mb. for June 1956, in units of 10^{-6} sec.$^{-1}$. Cyclonic vorticity and anticyclonic vorticity are considered positive and negative respectively and labeled C and A at centers. Note dominance of anticyclonic vorticity in the heat wave zone in central United States.

Temperatures were warm under anticyclonic circulation in the Southwest. Over Arizona, circulation changes from May were small, and persistence favored high monthly average temperatures, some of which are found in table 1.

4. PRECIPITATION

Precipitation presented a complex picture this month and its pattern, unlike that of temperature, could not all be fitted in neatly with monthly mean circulation. Factors combining to produce excess rainfall in the Pacific Northwest were a stronger than normal mean trough (fig. 1), especially in the first half-month (fig. 4A), and stronger than normal mean westerly flow (fig. 2) ascending over higher terrain. As the west coast trough shifted eastward at mid-month (fig. 7C), a frontal Low formed near Great Salt Lake (Chart X). This Low caused abundant rainfall as it moved northward, especially in northwestern Montana. Most of the rainfall from North

TABLE 3.—*New all-time record low temperatures for the month, established in June 1956.*

Date	Place	Temperature (°F.)
2	Evansville, Ind.	45
2	Grand Rapids, Mich.	35
2	Green Bay, Wis.	33
3	Birmingham, Ala.	46
3	Apalachicola, Fla.	58
3	Columbus, Ga.	44
3	Meridian, Miss.	45
5	Burns, Oreg.	28

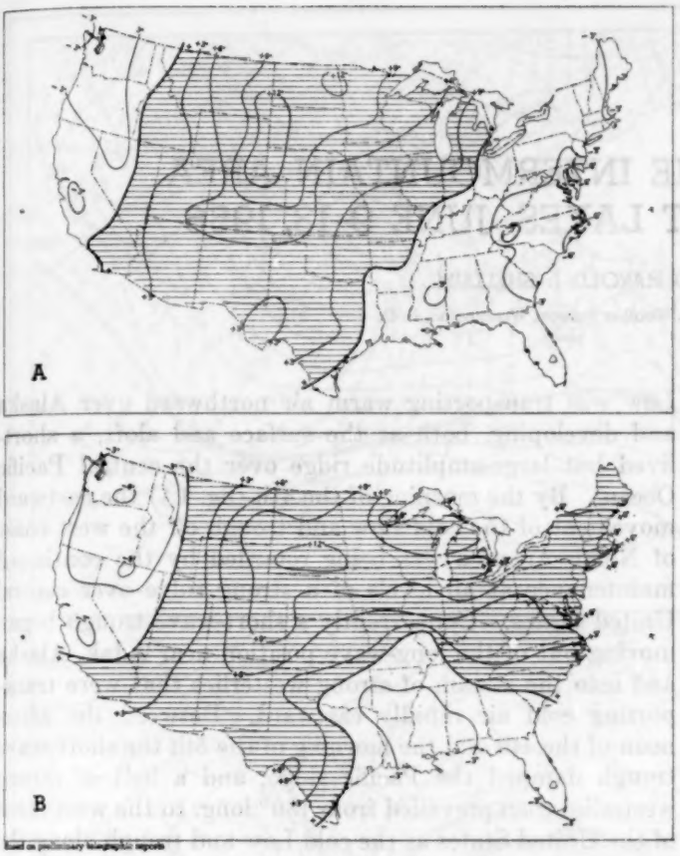

FIGURE 9.—Departure of average temperature from normal for the week ending midnight (A) June 10, 1956, and (B) June 17, 1956. Note warming in the Northeast and westward progression of cooling in the South. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. XLIII, Nos. 24 and 25, June 11 and 18, 1956.)

Dakota to Pennsylvania came as showers, mainly frontal in nature.

Frontal waves in early June added much to east coast totals, and net easterly 700-mb. departure from normal flow (fig. 4A) made a further contribution along the South Atlantic Coast. A finger of heavy precipitation (Chart III) protruding from the Gulf Coast to Arkansas was associated with the tropical storm (see track fig. 7C). Despite its small size and fairly weak winds (strongest, 45 m. p. h. at New Orleans, La., Airport), the storm dumped 3 to 9 inches of rain over southern sections of Louisiana, Mississippi, and Alabama to break developing drought conditions in the middle Cotton Belt.

Central Texas remained dry, with Abilene recording only 0.12 inch to bring the May-June total up to only 0.27. It was also dry in Arizona, where not even a trace was recorded at 5 reporting stations between the 4th and the 27th. However, substantial amounts fell thereafter over the eastern three-quarters of the State. Showers also increased over western Texas and New Mexico as strongly anticyclonic conditions relaxed during the latter half-month.

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THE HEAT WAVE FROM THE INTERMOUNTAIN AREA TO THE NORTHERN GREAT LAKES, JUNE 9–13, 1956

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1. INTRODUCTION

The average temperature of June 1956 was much above normal in the northern Plains region and normal or above from the southern Plateau region eastward to the Upper Great Lakes region. It was in the northern and central Plains region where the greatest departure from the monthly normal occurred, reaching a plus 9° F., at Rapid City, S. Dak. (Chart I-B). One of the principal factors contributing to this large departure of temperature was the heat wave of June 9–13, 1956, which extended from the interior of the Plateau region of the West into the Upper Great Lakes region. During this period of five days few monthly maximum temperatures were exceeded but numerous high readings for the day were equaled or new records established in the Northern Plains and Upper Mississippi Valley. The area of high temperature with which we are primarily concerned will be found within the plus 10° F. anomaly line (fig. 4B).

This heat wave was the first hot spell of the summer season and although not of long duration it presented several interesting facets for study. The development of the upper ridge that attended the heat wave furnished a rather good illustration of dispersion of energy downstream. This energy had great concentration just south of the western Aleutians early in June. Also, in conjunction with the dispersion of energy, there occurred a rapid cyclogenesis over the Gulf of Alaska and intensification of the trough off the western coast of the United States.

2. ANTECEDENT CONDITIONS

A deepening surface wave west of Japan on June 1 moved rapidly north-northeastward concomitant with a deepening 500-mb. trough moving eastward off the coast of Kamchatka. By the afternoon of the 2d, Greenwich time, the surface and 500-mb Low centers were in the vicinity of Adak, Alaska with central values of 960 mb. and 17,000 ft. respectively. During this same time the strong cold Low, both surface and aloft, near weather ship "Papa", 50° N. and 145° W., was being forced eastward toward Canada in a readjustment of wavelengths. Associated with these occurrences the Adak Low was transporting warm air northward over Alaska and developing, both at the surface and aloft, a short-lived but large-amplitude ridge over the central Pacific Ocean. By the morning of the 4th (fig. 1A) the eastward movement of the cold Low and trough off the west coast of North America was being retarded by the continued maintenance at all levels of a strong ridge over central United States. Concurrently a short-wave trough began moving out of the long-wave position near Adak, Alaska and into the stream of strong westerlies that were transporting cold air rapidly eastward. Between the afternoon of the 4th and the morning of the 5th the short-wave trough damped the Pacific ridge, and a belt of strong westerlies then prevailed from 180° long. to the west coast of the United States as the cold Low and trough along the coast had weakened and moved inland. This strong flow of westerlies prevailed through the 6th, but by 0300 GMT of the 7th slight cyclonic curvature had begun to develop near 150° W. (fig. 1B). This area of increased cyclonic vorticity continued to develop through the 1500 GMT chart of June 7. But changes of spectacular proportions were occurring prior to this time in the north central Pacific Ocean indicating that a definite readjustment was underway in the large-scale features of the circulation and that the strong westerlies would soon break down and the Pacific circulation would return to a more meridional flow.

This development occurred amain between the 5th and 6th in the formation of a pronounced ridge in the Adak area where previously the intense Low center had been located. This change at 500 mb. amounted to a 700-ft. rise of height in 12 hours, slightly in excess of 1,000 ft. in 24 hours, and 1,900 ft. in 84 hours. The 500-mb. height change chart for the 72-hour period ending at 0300 GMT of June 6 (fig. 1A), illustrates the magnitude of the tremendous energy involved in this development. During the 6th and 7th the long-wave trough off the west coast began to reintensify as the short-wave trough from the Aleutians approached the long-wave trough position. However, the principal intensification of the trough off the west coast, both at the surface and aloft, and the subsequent intensification of the pressure ridges over the central Pacific

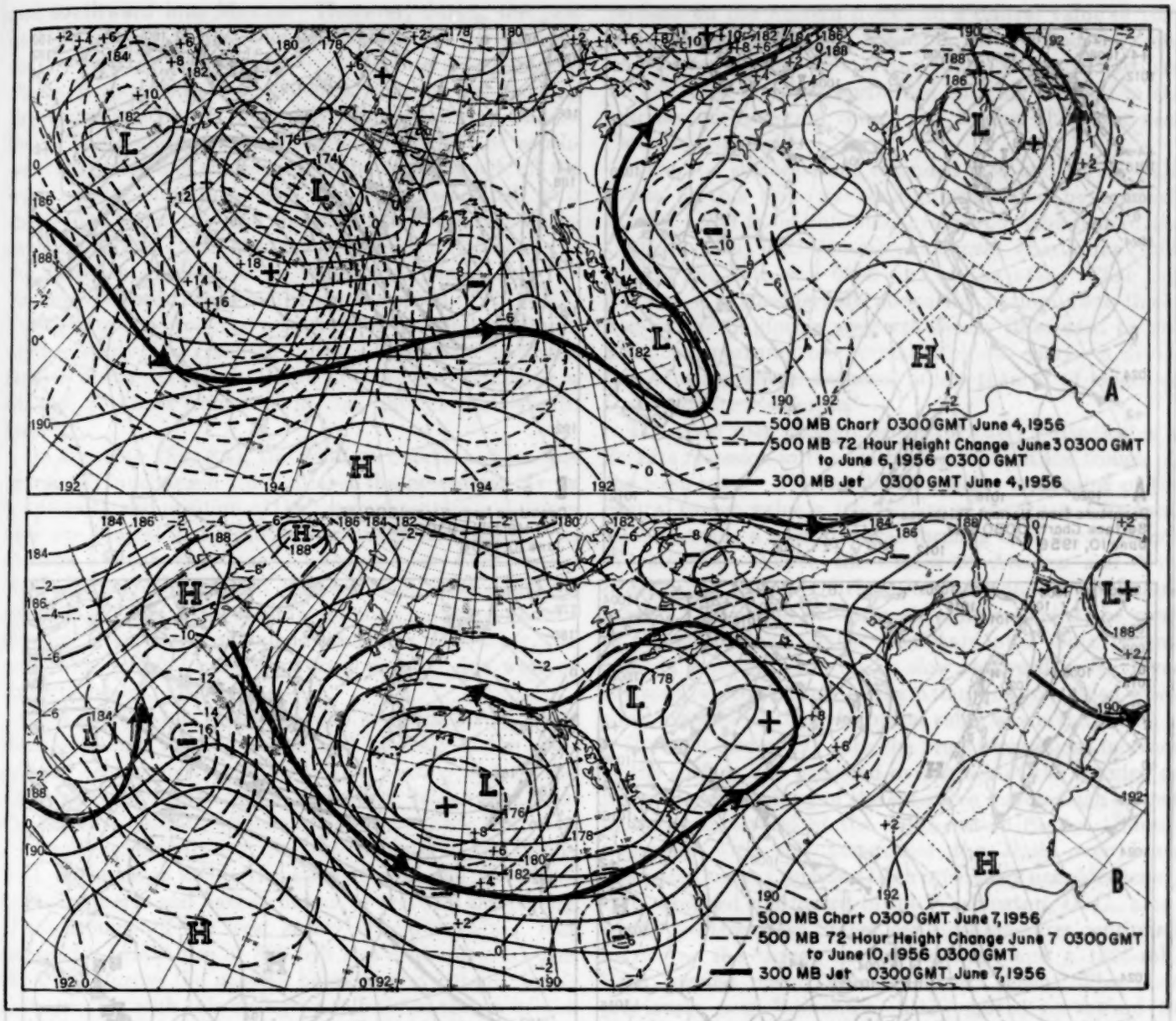
500 MB Chart 0300 GMT June 4, 1956
500 MB 72 Hour Height Change June 3 0300 GMT to June 6, 1956 0300 GMT
300 MB Jet 0300 GMT June 4, 1956
A
500 MB Chart 0300 GMT June 7, 1956
500 MB 72 Hour Height Change June 7 0300 GMT to June 10, 1956 0300 GMT
300 MB Jet 0300 GMT June 7, 1956
B

FIGURE 1.—(A) 500-mb. contours (solid lines) 0300 GMT, June 4, 1956 with height values in hundreds of feet. 300-mb. jet stream 0300 GMT, June 4 is indicated by heavy line with attendant arrows showing direction of flow. 72-hour 500-mb. height change for period 0300 GMT June 3 to 0300 GMT June 6 inclusive is shown by dashed lines. Height change values are in hundreds of feet with rise and fall areas indicated by plus or minus signs. (B) 500-mb. contours (solid) and 300-mb. jet stream for 0300 GMT, June 7, 1956. 72-hour 500-mb. height change (dashed) is for period 0300 GMT, June 7 to 0300 GMT, June 10, 1956 inclusive.

and the United States can be attributed in part to barotropic energy dispersion from the Pacific. Further discussion of this detail will be given in section 4 of this paper.

By afternoon on the 6th (GMT) several flat weak waves appeared on the east-west surface front extending across the Pacific Ocean. The front was in juxtaposition with both the strong westerly flow at 500 mb. and the 300-mb. jet stream. But it was the afternoon of the 7th before one of these waves indicated definite development as it began moving through the long-wave trough. That conditions were favorable for this wave to develop was clearly indicated by its proximity to a maximum of cyclonic vorticity on the 500-mb. chart. Strong cyclogenesis in the region of 45° N., 147° W. was also indicated on the Fjørtoft vorticity chart for 1500 GMT of the 7th. At the surface a well-defined temperature gradient existed across the front. Also, large 500-mb. height falls were moving into the area and these falls had increased to 800 feet during the 24 hours ending at 0300 GMT of the 8th. The development of this Low aided materially in the southward transport of cold air aloft off the central California coast and in the sharpening of the resulting trough. Later it was this front that brought cooler air in from the west and northwest to end the heat wave.

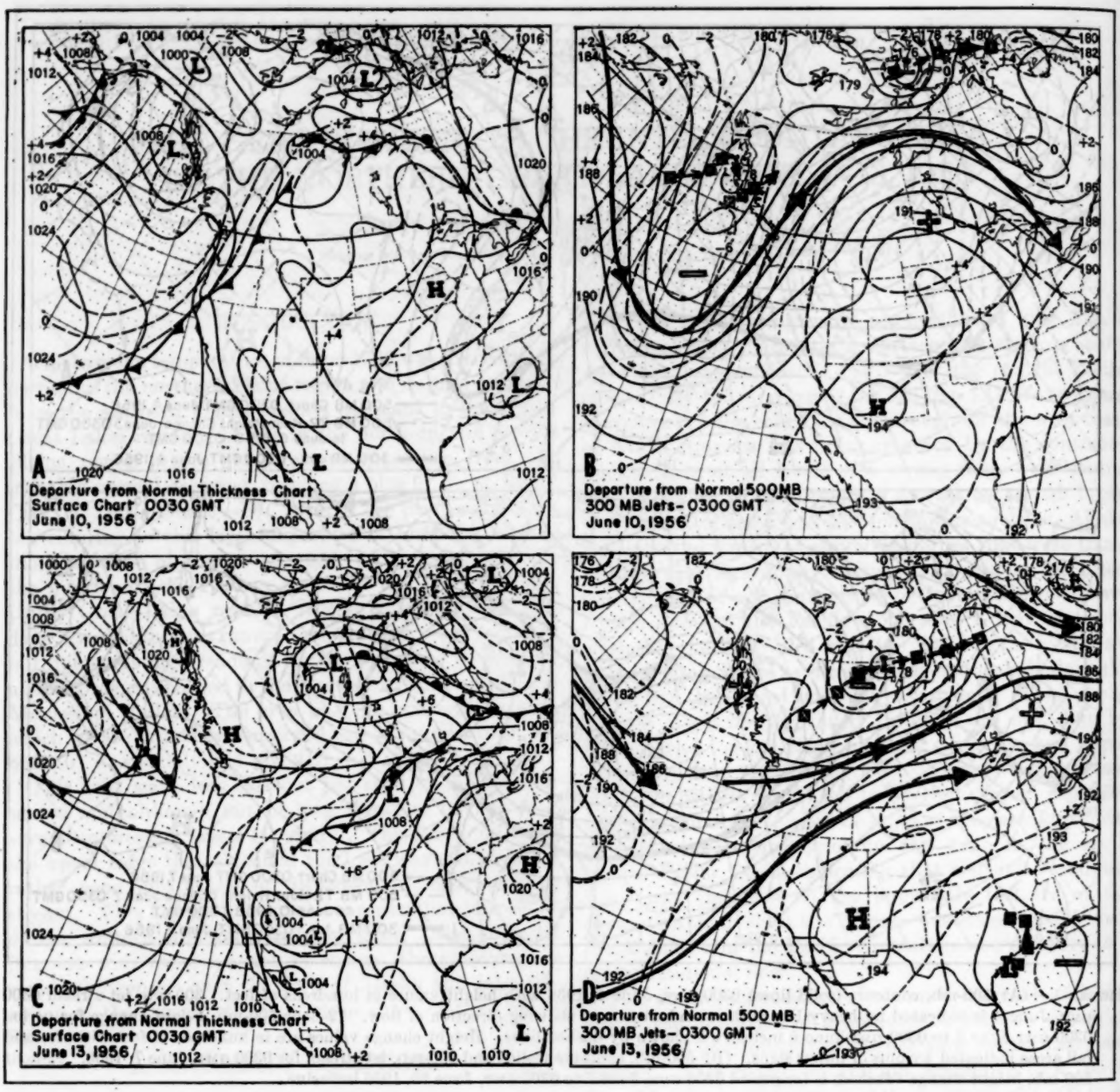

FIGURE 2.—(A) Sea level pressure pattern (solid lines) with fronts 0030 GMT and 1000–500-mb. thickness departure from normal (dashed lines labeled in hundreds of feet) for 0300 GMT, June 10, 1956. (B) 500-mb. pattern (solid lines labeled in hundreds of feet); 500-mb. departure from normal height (dashed lines labeled in hundreds of feet); and 300-mb. jet streams (heavy black line with arrows indicating direction of movement) all for 0300 GMT, June 10, 1956. 12-hourly center positions indicated for 36 hours prior to and after time of chart. (C) Same as (A) for June 13, 1956. (D) Same as (B) for 0300 GMT, June 13, 1956.

3. SYNOPTIC CONDITIONS, JUNE 9–13, 1956

By early morning of the 9th a flat high pressure system of 1019 mb. had become practically stationary over central Iowa. And during the previous 24 hours the cold front that had extended southwestward from the Low in the Moosenee, Ont., area dissipated as the Low weakened and moved southeastward. Simultaneously an occluded front moved onshore from British Columbia to northern Oregon, but the previously attendant Low center remained in the trough off the west coast. Indications of a building ridge were present in the vicinity of the Washington coast while in the extreme Southwestern States the heat Low persisted and extended into Mexico.

The upper air picture as reflected in the 500-mb. chart continued to show the 19,400-ft. contour over New Mexico

and southward into Mexico. However, during the past day the 500-mb. heights had increased to the north of the center, building a weak ridge over the Intermountain and Plains Region with the 19,200-ft. contour approaching the Canadian Border near the Montana-North Dakota line. This building was in conjunction with the southward extension and sharpening of the upper trough off the west coast. Simultaneously, the Low associated with this trough had moved 450 miles northeastward and weakened slightly. These changes produced a tightening of the pressure gradient over Vancouver Island and the Pacific Northwest, thus increasing the speed of the wind. Furthermore, it produced a backing of the wind to a more southwesterly flow resulting in the advection of warm air farther north. Tatoosh Island, Wash., was reporting a wind of 85 knots from 220° at this time at the 500-mb. level.

On the 10th (fig. 2A), the 0030 GMT surface chart was practically unchanged from that of the preceding day as to intensity and position of the pressure centers and fronts over the central and western portions of the nation. In Canada a weak Low was developing near Fort Smith, N. W. T., with the western occluded front moving into its center. Off the west coast a building anticyclone was moving toward the mainland and was displacing the weakening cyclone northward to a position due west of Annette Island, Alaska.

Aloft the 500-mb. chart (fig. 2B) also indicated a minimum of change in the position and intensity of the anticyclone center above southern New Mexico and of the cyclone center northwest of Vancouver Island and over the Queen Charlotte Islands. However, there had been a definite increase during the past 24 hours in the amplitude of the ridge above the Plains region and the Provinces of Alberta and Saskatchewan as well as a sharpening of the trough off the west coast. The Pas, Man., had recorded a height rise of 800 feet and a temperature rise of 12° C. during the past 48 hours at the 500-mb. level. Concurrently with this change, a fall of 600 feet in height and a temperature decrease of 13° C. had occurred in the trough near 40° N., 133° W. Winds had continued to back over the West Coast States and were now flowing from 180° to 200° with continued high speed.

By 0030 GMT of the 11th the surface chart indicated rising pressures over the Southeastern States as the subtropical High extended westward into the area. A weak High continued to be maintained over extreme southeastern Iowa or west central Illinois. Pressure gradient was quite flat over the eastern half of the country but increasing gradation was occurring over the western portion of the nation. This gradient intensification was most pronounced along the Pacific Coast States due in part to the troughing that was occurring southward along the occluded front and also to the eastward building of the high pressure cell west of the front. Surface pressures in the western portions of Washington and Oregon had risen 4 to 10 mb. during the past 24 hours. The Low attendant on the western front had a central value of 1002 mb., in the vicinity of Edmonton, Alta. And the front had moved to just east of the Idaho-Montana northern border, then streched southward entering Nevada in the extreme northwestern corner and leaving the coast near Santa Maria, Calif.

That the surface front extended into and across California at this time was well substantiated by approximately 1,200 ft. of thickness gradient to the rear of the front on the 1000–500-mb. thickness charts for 1500 GMT of the 10th and 0300 GMT of the 11th. That this amount was considerably above the normal June thickness in the California area was clearly illustrated by the 24-hour departure from normal thickness chart. A deviation of some 800 ft. occurred in less than 5° of longitude over northern California.[1]

The 0300 GMT 500-mb. chart for the 11th indicated a definite recession in the southern portion of the trough off the west coast. This produced a slight weakening of the central trough value in the vicinity of the Queen Charlotte Islands, while a new Low was forming over northwestern Washington. Above the States of Arizona and New Mexico the 19,400-ft. height line continued to be maintained. Advection of warm air aloft extended the crest of the anticyclone farther northward over south central Canada concomitant with its slow eastward drift. Over the southwestern sector of the Atlantic a continued westward advance of the subtropical ridge was maintained.

By 0030 GMT of the 12th the pressure gradient increase at the surface had persisted over much of the country as the western periphery of the extensive Azores High moved inland over several of the Southeastern States. Simultaneously with this occurrence the High over Iowa dissipated as the Canadian High previously near Moosenee, Ont., dropped southward to the Washington, D. C., area. In the Northwestern States, sea level pressures continued to rise as the trough moved eastward and a 1025-mb. High formed near Tatoosh Island, Wash. The Low previously near Edmonton, Alta., shifted northward to the Fort Smith, N. W. T. area and deepened. At the same time a new Low was in the process of development over the northern portion of Lake Winnipeg with the cold front extended from this Low to near Bismarck, N. Dak., then curved southwestward across Lander, Wyo., to Ely, Nev. with frontolysis occurring southwest of this station. Over the Southwestern States and Mexico the thermal Low persisted. The only new development indicated on the chart in this area was the formation of a weak Low over the Yucatan Peninsula.

In the upper air picture at 500 mb. the trough remained

[1] Due to the normal thickness gradient that prevails and frequently produces southerly thermal winds in excess of 50 knots over portions of California during the summer months when frontal structures may or may not be present, a slightly amended criterion for the placement of fronts in California has been developed. NWAC has recently developed an objective technique for use with the problems of frontal analysis in the California area. Objective study has shown that only when a distinct departure from normal thickness is indicated should fronts be carried across the southern and central portions of the State. At the present time this criterion is used by NWAC in determining occurrence of fronts in California.

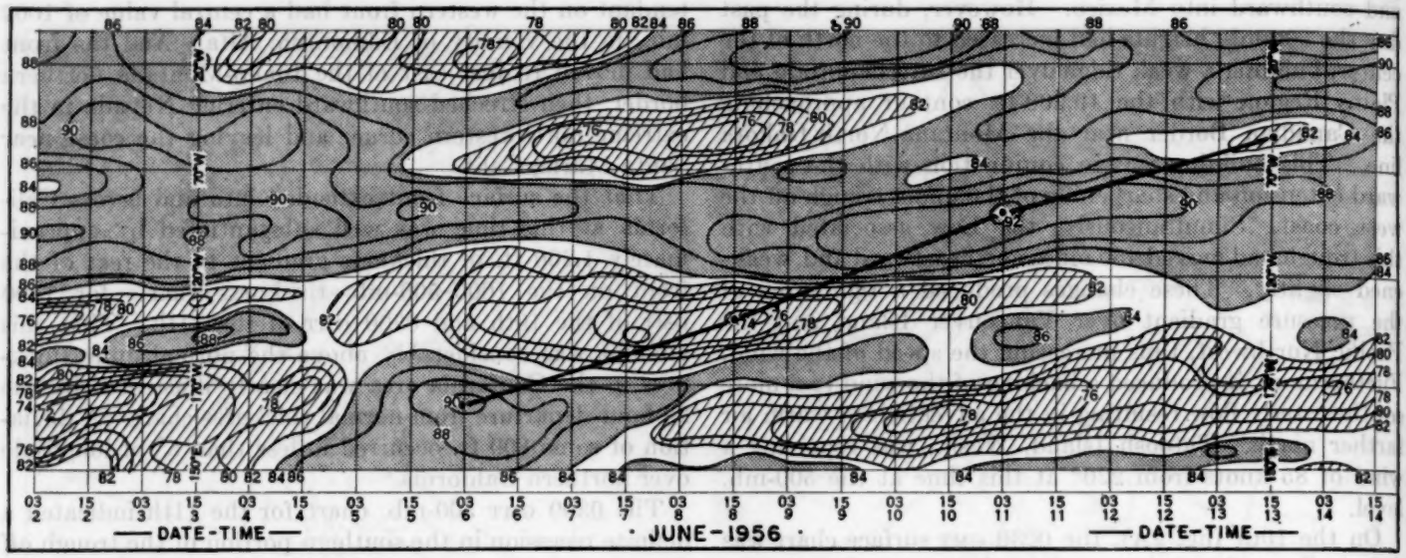

FIGURE 3.—Hovmöller diagram presenting a cross-section view of the 500-mb. constant pressure chart at 50° N. and extending from 150° E. to 5° W. during the period 0300 GMT, June 2, to 1500 GMT, June 14, 1956. Height values are in hundreds of feet but with the digit representing 10,000 omitted. The ridge areas are illustrated by stippling and the troughs by hatching. The heavy black line connecting alternate ridge and trough centers represents the trajectory of the dispersion of energy downstream.

along 131° W. but with weakening pressure gradient. An intensifying Low had moved over Alberta from Washington State during the past 24 hours with a central height value slightly under 18,000 feet. This development was moving eastward in the wake of the northern portion of the long-wave ridge over Canada and northern United States. Concurrent with these developments the subtropical ridge from the Atlantic joined with the ridge from the Southwestern States. And an upper Low attending an easterly wave began to intensify over the north-central portion of the Gulf of Mexico and the southern Mississippi Valley region.

In the early morning hours of the 13th (GMT) the surface chart (fig. 2C) presented a changing picture with the Low north of Lake Winnipeg weakening slightly as a deepening Low moved toward the Washington coast. The front associated with the old Low extended from International Falls, Minn., west-southwestward to the Great Salt Lake region. High pressure over the East was receding as the anticyclone near Washington, D. C., dropped south-southeastward and was located approximately 300 miles east of Jacksonville, Fla. The tropical Low from the Yucatan Peninsula had recurved and was moving northward toward New Orleans, La.

Deepening was occurring in the Low north of Lake Winnipeg on the 0300 GMT 500-mb. chart of June 13 (fig. 2D) as a strong westerly flow was damping the long-wave ridge from the James Bay region of Canada to the Great Lakes. The pivot point of the ridge line continued to be maintained over western Colorado. Over Illinois the northward movement of the trough from the Gulf of Mexico produced a separation of the Atlantic and the Continental ridges, while off the west coast the long-wave trough had practically disappeared.

Strong high pressure over western Canada was pushing southward to the rear of the old Low that had begun moving eastward across Hudson Bay during the 24 hours preceding the 0030 GMT chart of the 14th. By this time the surface front extended from Sault Ste. Marie, Mich., to Denver, Colo. High pressure over the East continued to weaken and yield ground to the deepening cyclones over the Western States and also off the Pacific Coast. In the States of Louisiana and Mississippi a weak tropical Low had moved north of New Orleans, La., spreading cloudiness and precipitation over a considerable area.

In the upper air, southern Canada was under a rather strong westerly flow by 0300 GMT of the 14th, while concomitantly the Arizona-New Mexico ridge was withdrawing southwestward from the Central States and the Atlantic subtropical High had receded to the southeastern coastal States. The tropical storm center was moving northward over central Louisiana with 500-mb. heights slightly less than 19,000 ft. A well-developed cyclonic flow was prevalent within 400 miles radius of its center.

4. DISPERSION OF ENERGY

One factor contributing to the heat wave of June 9–13, 1956 was the barotropic dispersion of energy downstream in the mid-tropospheric long-wave pattern. As previously mentioned, 500-mb. heights rose tremendously in the central Pacific Ocean during the 3-day period ending 0300 GMT, June 6, with a maximum rise of 1,800 ft. noted in the central Aleutians (fig. 1A). These rises were associated with a building ridge which reached its maximum intensity near 180° long., on the morning of June 6. The initial source of the energy associated with the building of this ridge appears to have moved out of Siberia. The

chain of events following the building of the ridge in the Central Pacific consisted of the deepening of the long-wave trough off the west coast of the United States (figs. 1B and 2B), the intensification of the ridge in the west central portion of the United States (fig. 2B), and the deepening of the Low near Newfoundland (fig. 2D). For a graphical picture the Hovmöller chart [1] provides a particularly good illustration of the dispersion of energy downstream (fig. 3). Note the regular interval of approximately 60 hours between the appearance of maximum amplitude development of alternate trough/ridge occurrence during the eastward progress of this energy.

Table 1 presents values of the observed speed of the dispersion of energy or "group velocity." A brief review of the concept of group velocity may be in order; Carlin [2] states, "If two sets of waves of slightly different wave length are traveling through a mediun and the velocity of the waves (phase velocity) is a function of the wave length, then one of the sets of waves will travel faster than the other . . . The velocity of the regions of reinforcement or interference is called the *group velocity* . . . The increase and subsequent decrease in wave amplitude is often observed to travel along a wave train at a rate much greater than the phase velocity of the wave, and it is this phenomenon which is believed to be directly associated with group velocity." Thus, the group velocity may be obtained by measuring the rate at which a maximum of amplitude travels through a wave train.

TABLE 1.—*Time, place and intensity of maximum anomalies illustrating progressive intensification downstream*

A. Using 5-day mean 700-mb. charts

Date	Lat. ° N.	Long. ° W.	Maximum anomaly (ft.)	Distance between centers (mi.)	Rate of dispersion (knots)
June 6	42	170	+480		
				1,680	28
June 8	55	132	−340		
				1,550	32
June 11	47	93	+280		
				1,460	20
June 14	60	58	−170		

B. Using daily 500-mb. departure from normal centers of action

Time GMT	Date	Lat. ° N.	Long. ° W.	Maximum anomaly (ft.)	Distance between centers (mi.)	Rate of dispersion (knots)
0300	June 6	46	174	+800		
					1,550	25
1500	June 8	48	138	−1,000		
					1,700	28
0300	June 11	53	94	+600		
					1,360	23
1500	June 13	56	55	−400		

C. Using the Hovmöller chart along 50° N. Lat.

Time GMT	Date	Long.	Distance between centers (mi.)	Rate of dispersion (knots)
0300	June 6	180°		
			1,500	25
1500	June 8	140° W		
			1,900	32
0300	June 11	90° W		
			1,360	23
1500	June 13	55° W		

Table 1 portrays the concept of group velocity in a more quantitative fashion. It is composed of data obtained from three different sources which were selected to determine the observed rate of energy dispersion downstream.

Table 1 Part A is based on a series of overlapping 5-day mean charts prepared in the Extended Forecast Section showing the distribution of the departure from normal of 5-day mean 700-mb. height. The time and place where centers of positive and negative departures from normal attained their maximum intensity have been determined by interpolating among these charts. The rate of energy dispersion or group velocity results when the linear distance between centers is divided by the time interval between their occurrence.

Part B is based on the time and place where daily 500-mb. departure from normal centers of action reached their greatest intensity. Again, the linear distance between centers is divided by the time interval between their occurrence to obtain the group velocity.

Part C is based on the time and place of progressive amplification propagated downstream in the troughs and ridges represented by the Hovmöller chart (fig. 3). Group velocity is then obtained in the same manner as above.

Values obtained for group velocity were strikingly similar in all of the three methods used. From the ridge in the central Pacific to the trough off the west coast the rate of energy dispersion averaged 25 to 28 knots, while from the trough to the next ridge in the west central United States the average was 28 to 32 knots, and from this ridge to the next impulse, near Newfoundland, the average was 20 to 23 knots. These values seem consistent with studies made previously. Carlin [2] made a study of a winter case where the group velocity averaged near 40 knots. Klein [3] found in a summer month (August 1953) that these speeds averaged near 18 knots, or about half of the value obtained by Carlin. Since the rate of energy dispersion depends directly on the zonal index, smaller values in summer should be expected. In this case the values observed, being between those obtained by Carlin and Klein, would seem reasonable since June would normally have a lower zonal index than a winter month but probably not as low as the warmest months of July and August.

5. PLANETARY PATTERNS AND ANOMALIES FOR HEAT WAVES

There are several features of the planetary wave pattern that are known to be essential for the development and occurrence of a summer heat wave over the United States. Some of these features are: First, a long-wave trough of strong intensity and amplitude must be present for the transport of warm air northward. Second, there must be an almost simultaneous building or intensification of a long-wave ridge immediately east of the long-wave trough

position. Third, the departure from normal heights in the long-wave troughs and ridges must be large. Fourth, stagnation of these features is essential for a long-period heat wave.

Previous articles by Klein [4], Winston [5], Hawkins [6], and Holland [7], have shown certain conditions to be necessary for the occurrence of much above normal summer temperatures over the United States. The location and intensity of the mean 700-mb. long-wave troughs and ridges were most important in determining the area of greatest surface deviations from normal. In most of the cases discussed by these authors the axis of positive departure from normal of the 700-mb. heights has been along an east-west or northeast-southwest direction over the United States with the maximum attendant temperature deviation having occurred along this axis. The associated long-wave trough negative anomalies have been inland over the extreme Western States. The result of this has been that most of the recent heat waves have prevailed over South Central and Eastern United States rather than over the North Central and Western States. In this regard a summary will show that during the past 10 years more than half of the Junes have shown above normal temperature averages for the month in most States east of the Intermountain Region and west of the Appalachian Mountains. The States within this area that did not conform to this pattern are Montana, North Dakota, and South Dakota, all located in the northern Plains region, where 6 or more of the last 10 Junes have been below their normal temperature. In the middle portion of the Mississippi Valley, Iowa and Illinois have had an equal number of warm and cold Junes during this 10-year period. Texas has had a preponderance of warmer than average Junes with a ratio of 8 to 2 for the past decade, while New Mexico, Oklahoma, Arkansas, Louisiana, and Mississippi have had 7 of the past Junes with above normal temperatures. Over the Eastern States the ratio has also been approximately 7 to 3 for above normal temperatures.

These areas in the United States that have experienced much above normal monthly temperatures during the month of June during recent years also have had a positive anomaly on the 700-mb. monthly mean chart ranging from nearly 100 to 200 feet. During the same years that excessive June heating occurred there has been an almost equally large negative anomaly along or over our west coast. This relationship between temperature and the circulation aloft has been quite well covered by Martin and Hawkins [8].

6. PLANETARY PATTERN AND ANOMALIES FOR JUNE 8–14, 1956

In the preceding article by Green [9], the ridge line on the 700-mb. mean height chart for the month of June, as well as the axis of the area of positive departure from normal of the 700-mb. mean chart, is in a more nearly north-south direction than in the cases previously mentioned. On the departure of average temperature from normal chart for June 1956, (Chart I–B) it can be seen that the axis of the maximum positive anomaly is parallel to but slightly west of this ridge line. Green [9] also has presented the mean 700-mb. chart for June 1–15 along with its anomaly, (his fig. 4A). Note that the ridge line and axis of greatest departure from normal on this chart are nearer to the axis of maximum temperature departure for June, as would be expected with the heat wave having occurred during the first half of the month. These charts also locate the long-wave trough position several degrees west of the Pacific Coastal States thus allowing the long-wave ridge pattern to be maintained farther west and so permitting the warm air with resultant high temperatures to flow over the Northern Plains and into central Canada. The 6° F. positive anomaly of the departure from normal temperature for June extended northward across central Saskatchewan, and the 4° F. positive anomaly extended into northeastern Alberta, to nearly 60° N.

With monthly anomalies indicating large deviations it must be expected that during a short-period heat wave daily charts would show considerably larger departures from normal. In order to make daily anomaly comparisons it is necessary to use the 500-mb. departure from normal charts. At this level the deviation approaches twice the 700-mb. value. The 700-mb. departure from normal chart for June 1956 (see preceding article by Green, fig. 1) had a positive anomaly ranging from 120 ft. near Salt Lake City, Utah, to 150 ft. near Duluth, Minn.

At 0300 GMT the 500-mb. height anomaly charts for June 8 and 9 indicated a negative value in excess of 800 ft. west of Vancouver Island and moving east-southeastward, with a growing positive area exceeding 200 ft. spreading over the Intermountain and Plains regions. By 0300 GMT June 10 the negative departure had changed from an east-west to a north-south elongation off the west coast and extended from 25° N. lat. across the North Pole. A central negative area in excess of 600 ft. was west of Oregon while the area of positive anomaly, now in excess of 400 ft. continued to spread over central North America (fig. 2B). During June 11 and 12 the negative anomaly area shrank in size, recurved, and moved northeastward into southwestern Canada but the central value continued in excess of 400 ft. Concomitantly the growth of the upper ridge and its slow eastward progression produced positive anomalies in excess of 600 ft. centered in an area north of International Falls, Minn., and west of Moosonee, Ont. On the 13th and 14th the area of negative departures, with central values continuing in excess of 400 ft., advanced east-northeastward into central Canada. The area of positive anomalies remained practically stationary but with central values decreasing to slightly above 400 ft. (fig. 2D). It was at this time that the ridge line obtained a more east-west orientation with the pivotal point continuing over Utah and Colorado as the heat wave was now spreading into the Northeastern States.

Generally during this period, the area of departure from the normal thickness (1000–500 mb.) was in close agreement with the 500-mb. height anomaly as to intensity and area. This would indicate that the surface pressures and the 1000-mb. height values were in close agreement with the normal values. The one exception of any note was on June 13 when a tropical storm moved into the New Orleans, La., area. At this time the 500-mb. anomaly chart had a negative area in that region while the 1000–500-mb. thickness anomaly chart remained unchanged. This would indicate that both surface pressure and 500-mb. heights were falling at a uniform rate.

As has previously been stated the area of high temperatures with which we have been concerned is the region where readings were 10° F. or more above the monthly normal maximum as shown by fig. 4B. It is interesting to note that the area of daily highest temperature for the period shown on fig. 4A is for the most part in rather good agreement with the axis of departure from normal of either the 500-mb. constant pressure or the 1000–500-mb. thickness chart. The approximate position of these ridge lines of the positive anomalies can be observed for the high temperatures of the 9th and 12th by reference to fig. 2A, B, C, D. Furthermore, these charts tend to illustrate that the pivotal point of the ridge line of the positive departures from normal occurred in the States of Utah, Nevada, and western Colorado indicating why the heat wave spread over the greater portion of the Northern States.

The same correlation between the ridge line of the positive anomalies and the high temperature carried throughout the entire heat wave. There was very little to choose from as to the position of the ridge line on the departure from normal of the 500-mb. chart or the 1000–500-mb. thickness chart. Temperatures of 10° F. or more above the monthly normal maxima almost invariably were associated, as would be expected, with values 200 ft. or more above the monthly normal for the 500-mb. height and the 1000–500-mb. thickness, thus indicating a good use for 500-mb. prognoses as an aid in the forecasting of maximum temperatures for the next day or two.

The jet stream during this period of hot weather was carried over Canada far to the north of its normal June position as may be observed on fig. 2B and fig. 6 of Green's preceding article. It was not until near the end of the heat wave that the jet returned to a more normal position. During this period the cyclonic developments were, as normally would be expected, carried well to the north of the United States and occurred to the left of the jet stream thus retarding cooling over the hot northern States and southern Canada.

7. ANOMALIES OF THE 500-MB. PROGNOSTIC CHARTS, JUNE 10–14

A comparison was made between the departure from normal heights of the actual 500-mb. charts and the NWAC 36-hour 500-mb. prognostic charts. The 0300 GMT charts were again selected for comparison as this was the upper air observation nearest to the maximum heat of the day.

Graphical subtraction using acetate overlays requires only a minute or two for obtaining the prognostic departure from normal for an area the size of facsimile section 1. The anomaly height chart of June 10 indicated that the 36-hour prognostic 500-mb. map had height values too low in the Northwestern States and because of this difference the prognostic positive anomaly ridge line was some 300 miles south and east of its actual position. Thus on this prognostic chart the probable occurrence of high temperatures was indicated east and south of the area where the high readings actually occurred.

By 0300 GMT of the 11th the prognostic departure from normal height chart for the 500-mb. level was in much closer agreement with the actual anomaly chart as to intensity and area covered as well as to the location of the ridge line. And on this prognosis the area of maximum temperatures in excess of 10° above the June normal maximum for each station was practically within the 200-ft. positive anomaly line.

The 0300 GMT height anomaly derived from the 500-mb. prognostic chart of the 12th again presented values much too low in the Western States but there was good agreement between prognostic and observed anomalies over south-central Canada and the Great Lakes region. From this chart it would have been difficult to foresee the band of high temperatures from near Elko, Nev., to Rapid City, S. Dak. However, the remaining area of high temperatures might have been expected.

The departure from normal prognostic charts on the 13th at 0300 GMT present about the same difficulties as encountered on the 12th: the tendency for too low height in the West favoring lower temperatures in the States of Nevada, Utah, and Wyoming than did occur. But in the north-central portion of the country there was excellent agreement between the prognostic ridge line and the area of high temperatures.

The prognostic departure from normal chart derived from the 36-hour 500-mb. prognosis for the 14th was in almost complete agreement over the United States and Canada with the actual 500-mb. height anomaly chart. Thus the area of expected maximum temperature was quite clearly defined.

It may be seen that, for the most part, the use of these prognostic charts could be of some aid in the forecasting of movements of maximum temperature areas. Generally these 500-mb. prognostic charts were normal to slightly below average in regard to accuracy according to NWAC verification system.

8. DISTRIBUTION OF MAXIMUM TEMPERATURES

The pattern produced by charting the date of occurrence of maximum temperature at each station during the period of June 9–13, 1956, is depicted by figure 4A. Date

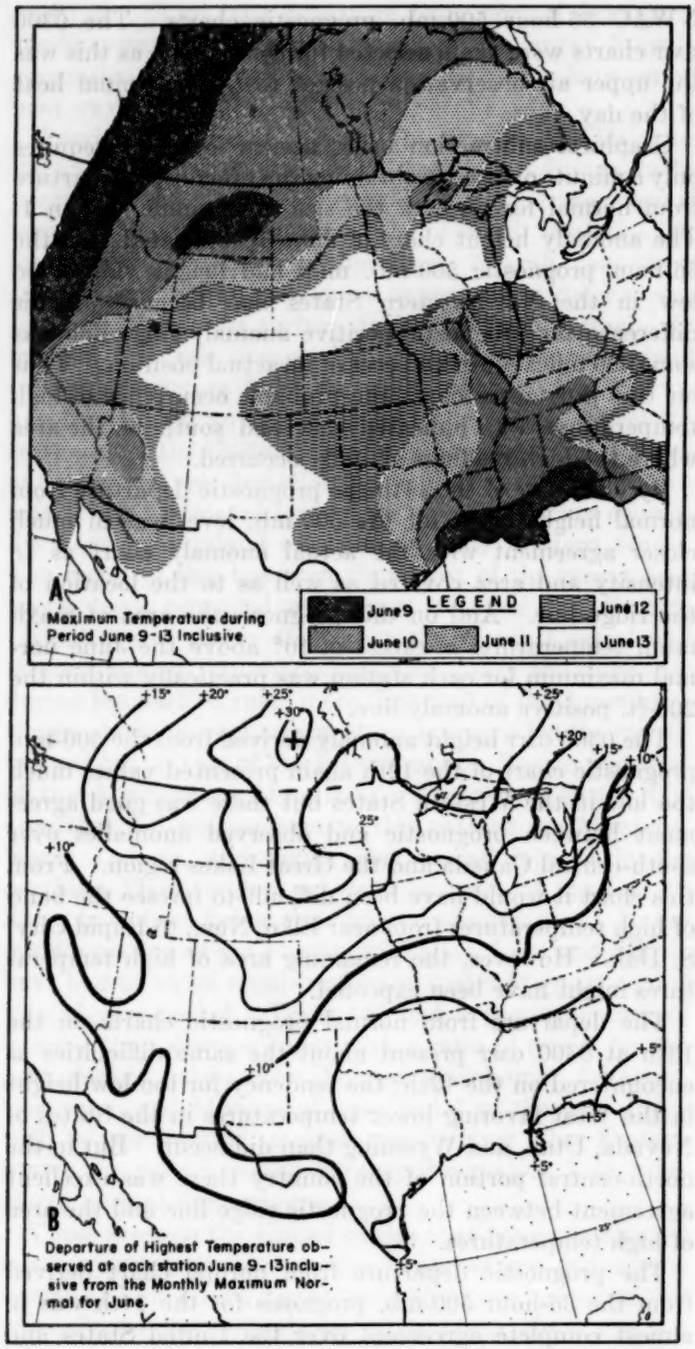

FIGURE 4.—(A) Date of maximum temperature occurrence during period of June 9–13 inclusive. Shading of different types has been used to distinguish different dates (see legend on chart). It is of interest to note the convergence of these dates bands of highest temperature into the white ribbon depicting the area of high temperatures on June 13, 1956 prior to the cooling that occurred on the 14th. (B) The departure of the highest temperature reported from June 9–13 inclusive from the maximum monthly normal at first order stations with lines of equal anomaly at intervals of +5° F. Maximum departures are found in the North Central States and southern Canada. The line of greatest departure, +10° F., encloses the heat wave area considered in this paper.

of occurrence of the highest temperatures during this period is indicated by the different shadings. On June 9 the highest readings were confined for the most part to the Northwestern States and the central Coastal States along the Gulf of Mexico. Each successive day the areas of maximum temperature advanced toward each other with the largest area of maximum temperature in the United States occurring on June 12. The chart shows quite clearly the gradual concentration of maximum temperatures by June 13 into a ribbon-like area extending from Mexico northward into southern Wyoming, then curving east-northeastward across the Plains into the Upper Great Lakes region before spreading fan-like over the central portion of eastern United States.

That the maximum temperatures occurred early in the period over the Northwestern States is easily understood from the synoptic situation. On June 10 (fig. 2A) a frontal system was oriented northeast-southwest across eastern Washington and central Oregon. Maximum temperatures were reported in advance of this front. Cloudiness and cooler air attended the slow but persistent eastward and southward movement of this front. Its passage brought an end to the high maximum readings. By 0030 GMT, June 13 (fig. 2C) the front had reached a position extending from International Falls, Minn. southwestward across central South Dakota and through central Wyoming.

The northward and westward spreading of afternoon high temperatures from the Gulf region is somewhat more difficult to explain. Charts at the 850-mb. level June 10 indicated a weak easterly wave moving slowly across the Gulf of Mexico and on June 11 this wave extended into the eastern Gulf States. Note the small surface Low centered in Alabama in figure 2A. Circulation was weak but easterly winds and cloudiness may have aided in keeping the area of highest temperature farther north and west. By the 12th and the 13th thickening cloudiness and precipitation from a small tropical storm moving northward through the central Gulf of Mexico kept temperatures relatively low throughout the central Gulf States.

Actual values of maximum temperatures that occurred during this period have not been published with this article for two reasons: First, few monthly or yearly extreme values were equalled or exceeded at first-order stations, and second, it was thought that the departure from normal of the monthly maximum temperatures for June would be more revealing as to the region where the heat was most concentrated. Figure 4B shows the departure of highest temperature observed June 9–13, 1956 from the monthly normal maximum for June at each station. This chart indicates very clearly that the greatest departures were in the northern tier of States extending from Idaho to Michigan, with another axis appearing to extend northeastward from Yuma, Ariz. Greatest anomalies, with temperatures of 25° F. or more above the monthly normal maxima occurred in South Dakota, west-

TABLE 2.—*First order stations reporting record temperatures from the northern Great Lakes westward, June 9–14, inclusive*

Station	June						
	8	9	10	11	12	13	14
Cheyenne, Wyo.	H			E	H	H	
Casper, Wyo.	H	H	H	H	H	H	
Duluth, Minn.		H	H		H		
Sioux Falls, S. Dak.		H		H	H	H	
Huron, S. Dak.		H			H	H	H
Billings, Mont.		H	H				
Salt Lake City, Utah		H	H				
Mobile, Ala.		H					
Madison, Wis.		H	H	H	H	H	
Helena, Mont.			H				
Regina, Sask.			R				
East Lansing, Mich.				H	H	H	
Pueblo, Colo.				H	E	E	E
International Falls, Minn.				A			
Muskegon, Mich.				H			
Marquette, Mich.					H	H	
Escanaba, Mich.					H		
Milwaukee, Wis.					H	H	
Chicago, Ill.					H	H	
Toledo, Ohio					H	H	H
Kapuskasing, Ont.					A*		

H = Highest for date.
E = Equalled highest for date.
A = Absolute highest for the station.
R = Record for month.
*Apparent from available data.

ern North Dakota, a large portion of south central Canada, northeastern Minnesota, and Upper Michigan.

The high temperatures reported during the period June 9–13, 1956, aided materially in making this June one of the warmest on record at many of the stations over the eastern half of the Intermountain region, the north central and northern Plains region, the Upper Mississippi River Valley and the upper Great Lakes region. Your attention is called to table 1 in the preceding article by Green [9] which provides a summarization of these temperatures for the month of June.

Table 2 has been compiled from Local Climatological Data for June to indicate stations within the area that reported temperatures which equalled or exceeded the daily maximum during the period selected. The absolute maximum temperature at International Falls, Minn. was exceeded by one degree when a reading of 98° F. was reported on June 11.

9. CONCLUSION

It might be well to state that while it is practically essential that the 700-mb. and 500-mb. height be above normal for the formation of a heat wave condition, this fact by itself is not sufficient in the development of an above normal temperature area.

An excellent example of a large positive 500-mb. height departure and 1,000–500-mb. thickness departure from normal associated with low surface temperatures occurred this June over northern Canada with the central area of departures in the vicinity of 74° N. and 95° W. In this region the positive anomaly values exceeded 1,000 ft. for short periods but generally the anomaly ranged from 600 ft. to over 1,000 ft. above normal from June 20 to June 30 inclusive for the 500-mb. height and the 1,000–500-mb. thickness. However, during this entire period the afternoon maxima ranged from the upper thirties to the middle fifties. That the afternoon temperatures should remain so low during these conditions was due to the cold water in the surrounding area that kept the lower lapse rate stable. The temperature average for the month of June in this Canadian area was below normal.

Furthermore during heat waves these conditions also should be present over a large area. There should be uniformity in the height and thickness anomalies of the various levels indicating a nearly normal and flat surface pressure area. The air mass must approach the dry-adiabatic lapse rate and not be of a stable air mass type. Little or no moisture should be indicated by the upper-air soundings as the sky must be practically cloudless. In addition there should be a high probability of these conditions being or becoming stagnant over the area.

ACKNOWLEDGMENTS

The writers wish to express their appreciation to the staff members of NWAC for helpful suggestions and the reviewing of the article; to the Daily Map Unit of the Weather Bureau for detailed drafting of the figures.

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200- AND 100-MB. CHARTS

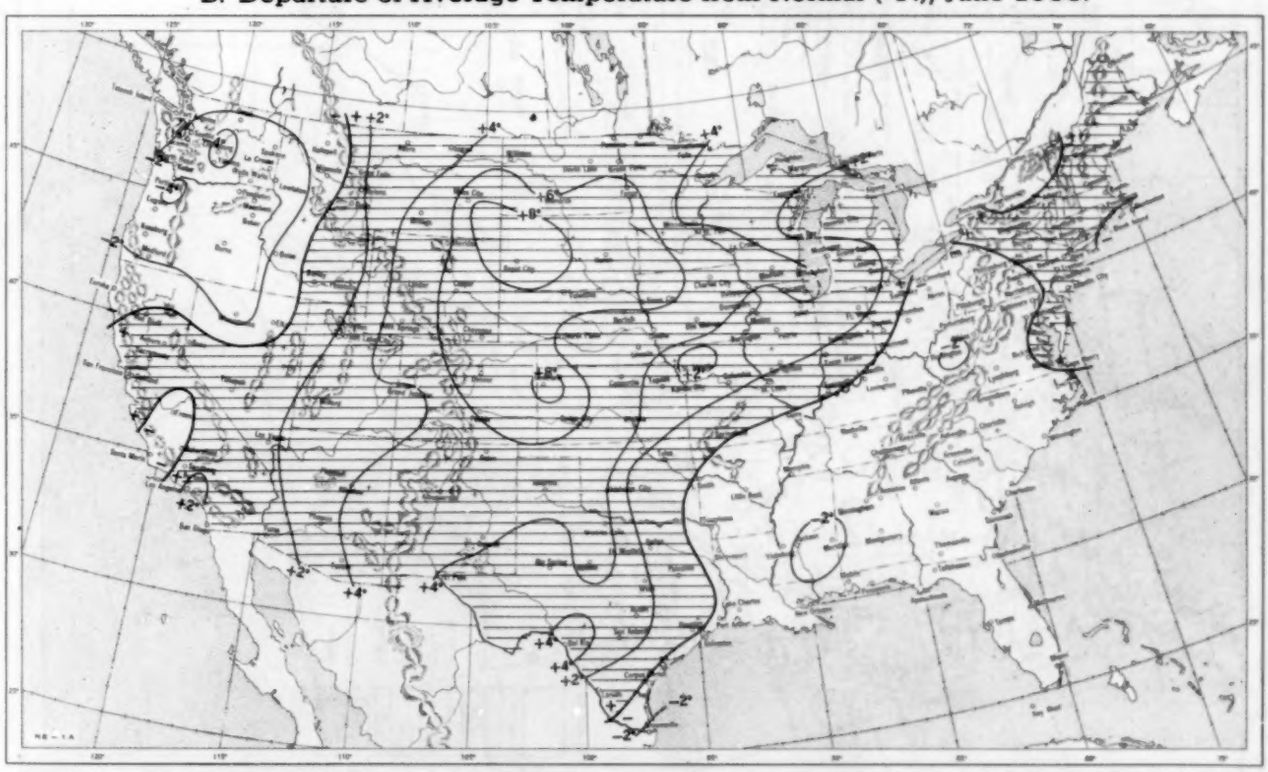
Meteorological data for higher and higher levels of the atmosphere are becoming more plentiful and it is believed that sufficient data are now available to warrant a monthly analysis at 200- and 100-mb. levels. Therefore, beginning with this issue, 200- and 100-mb. charts will be included with the upper air mean charts at the end of each issue. These charts, XVI and XVII, are similar in all respects to Charts XII–XV except that there are no pibal winds at 200 and 100 mb.

IT SHOULD BE NOTED that with this issue there is a change in the manner of plotting the resultant winds on Charts XII–XVII. The winds shown in red are from rawin reports and are for the same level as the contours and isotherms. The winds in black are from pibal reports at 2100 GMT and are for the nearest standard height level. In addition, wind speeds are indicated in knots: a flag equals 50 knots, a full barb 10 knots, and half barb 5 knots.

U. S. GOVERNMENT PRINTING OFFICE: 1956

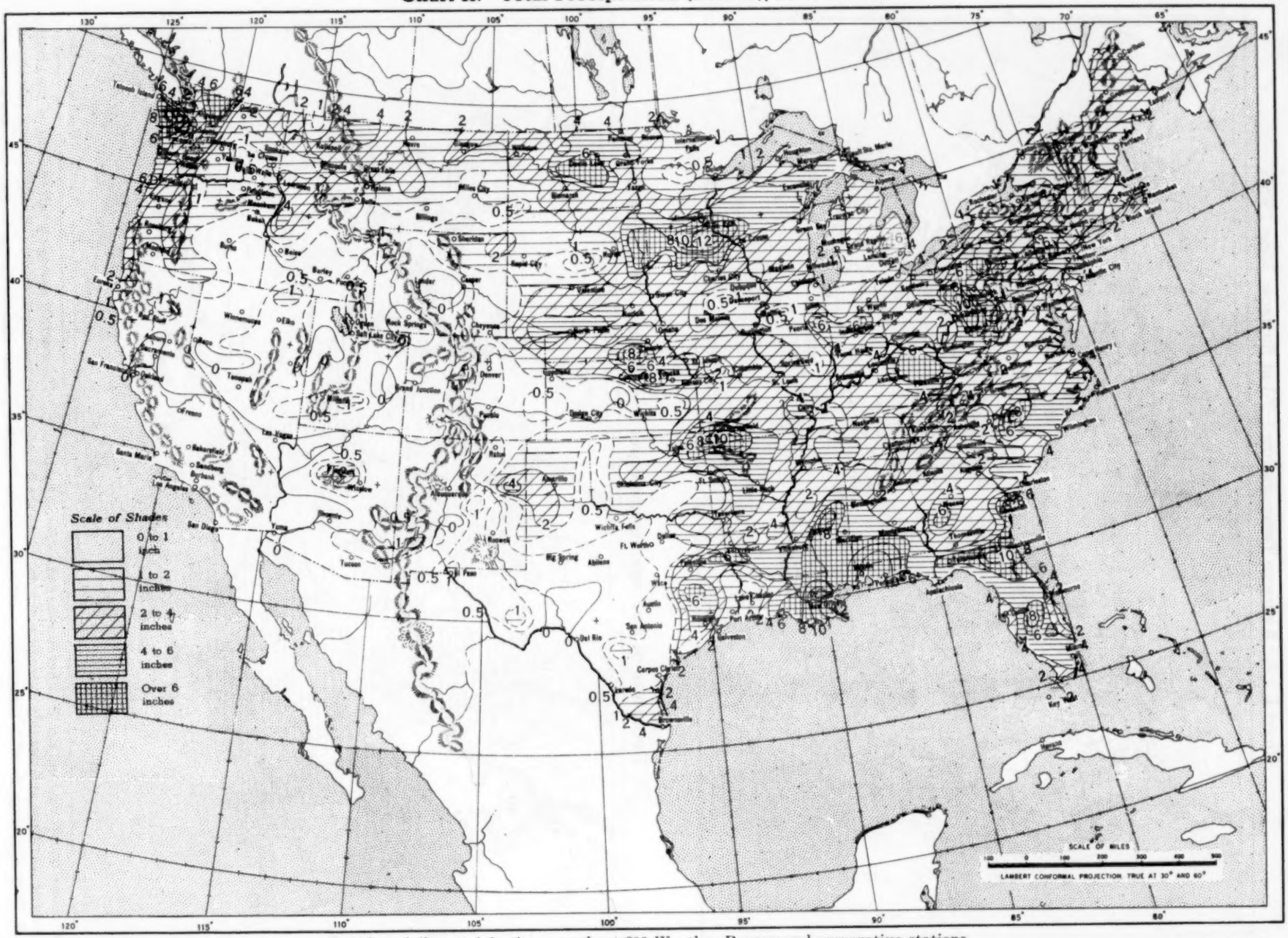
Chart I. A. Average Temperature (°F.) at Surface, June 1956.

B. Departure of Average Temperature from Normal (°F.), June 1956.



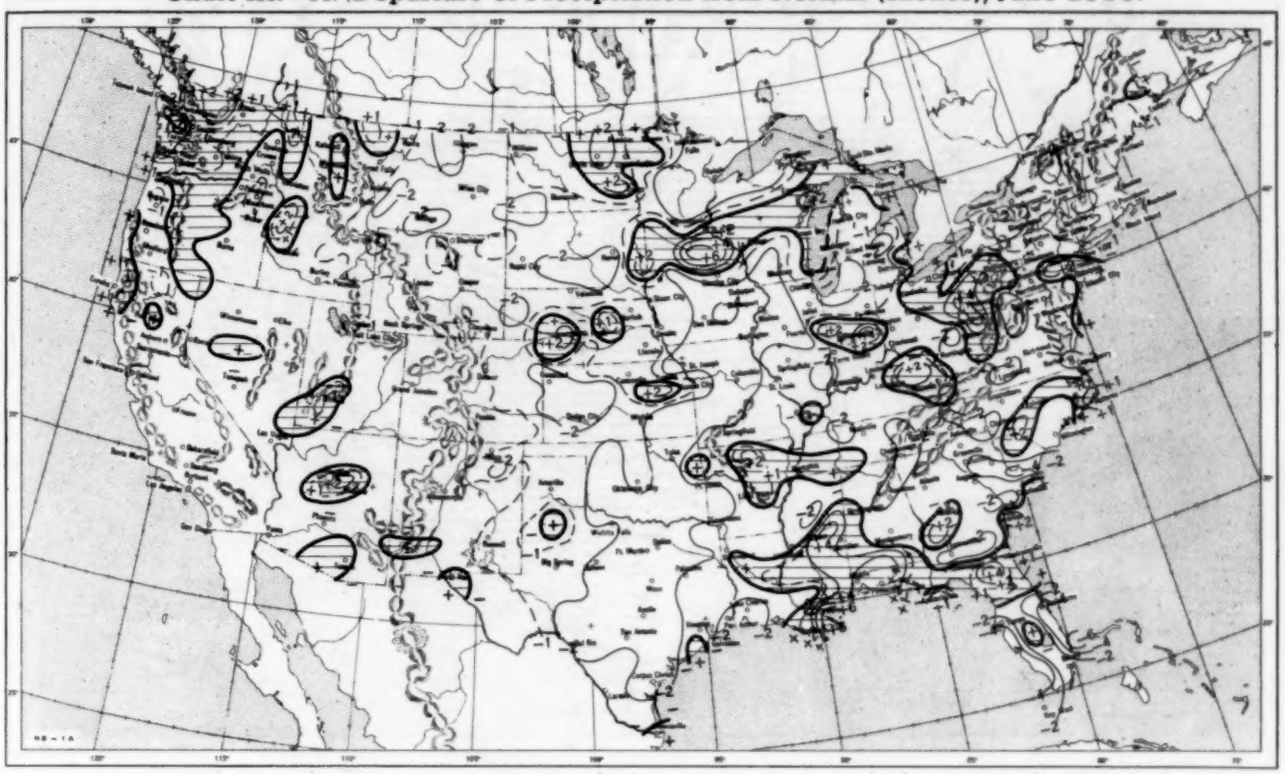
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), June 1956.

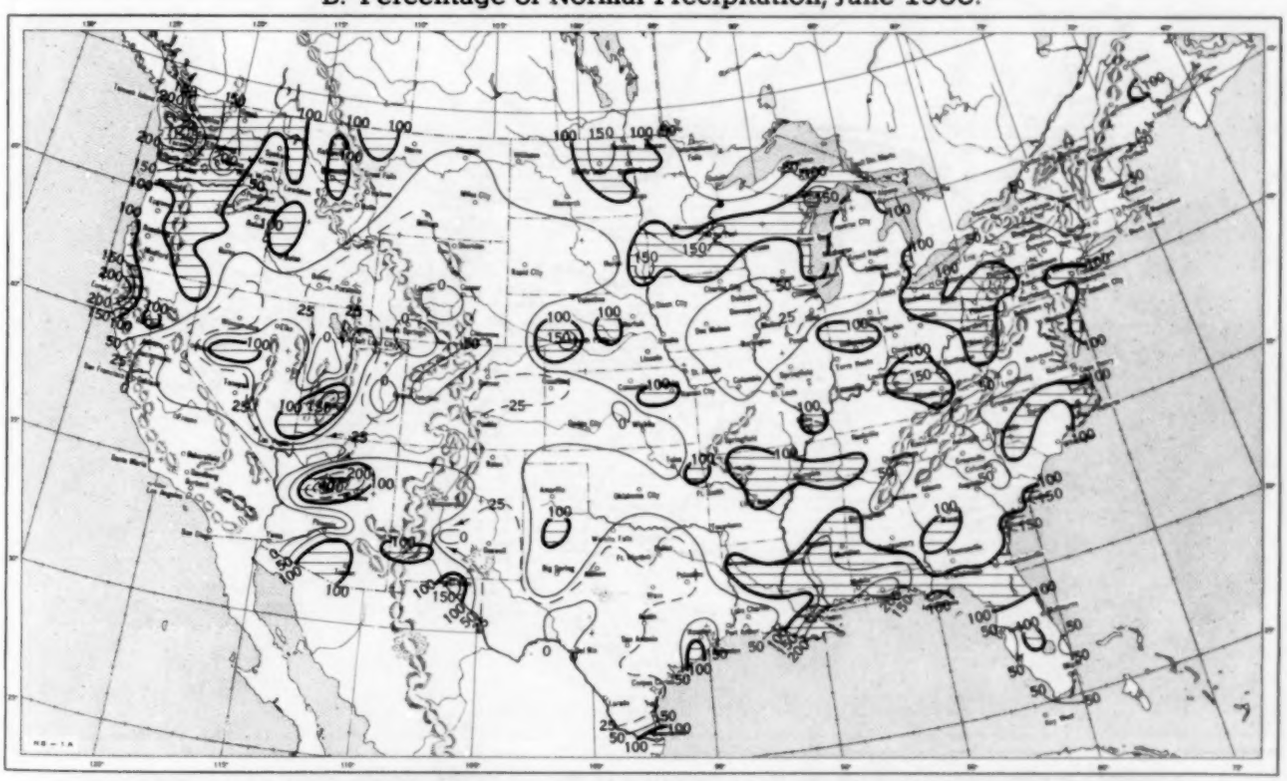

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), June 1956.

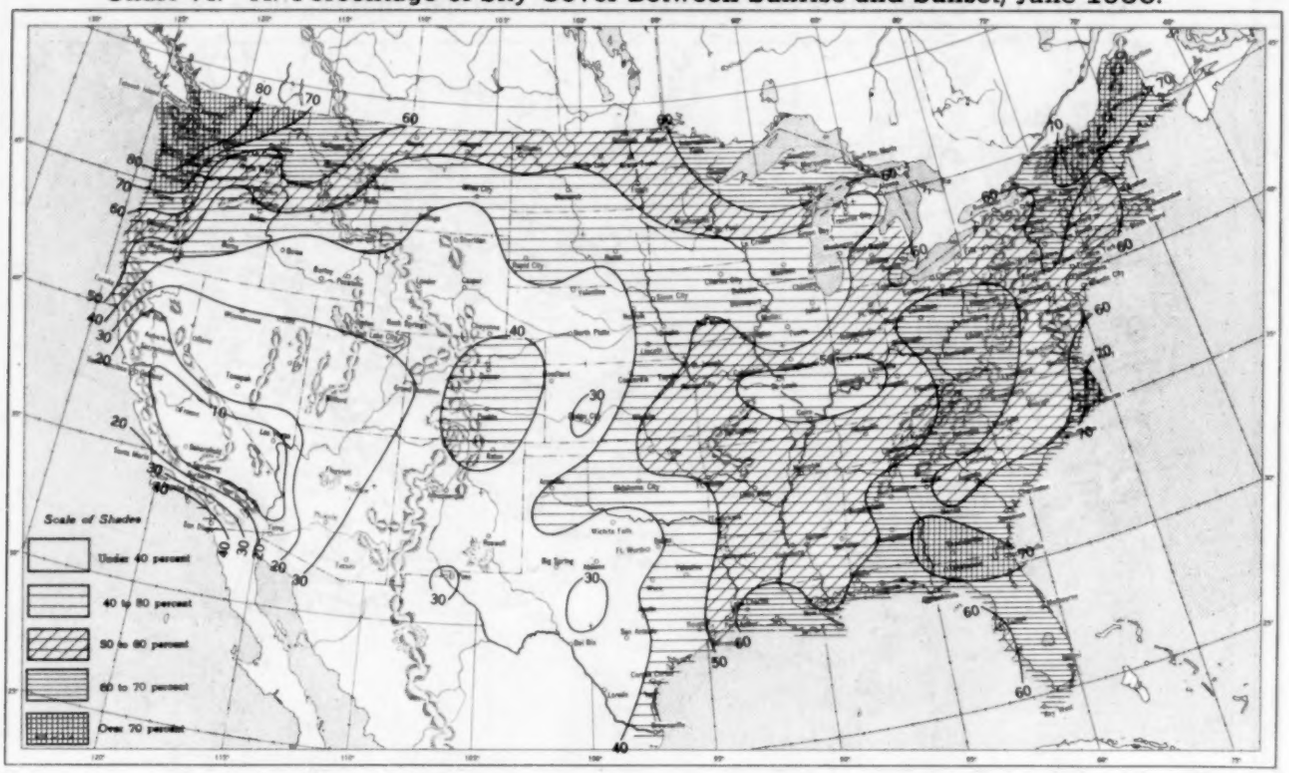


B. Percentage of Normal Precipitation, June 1956.

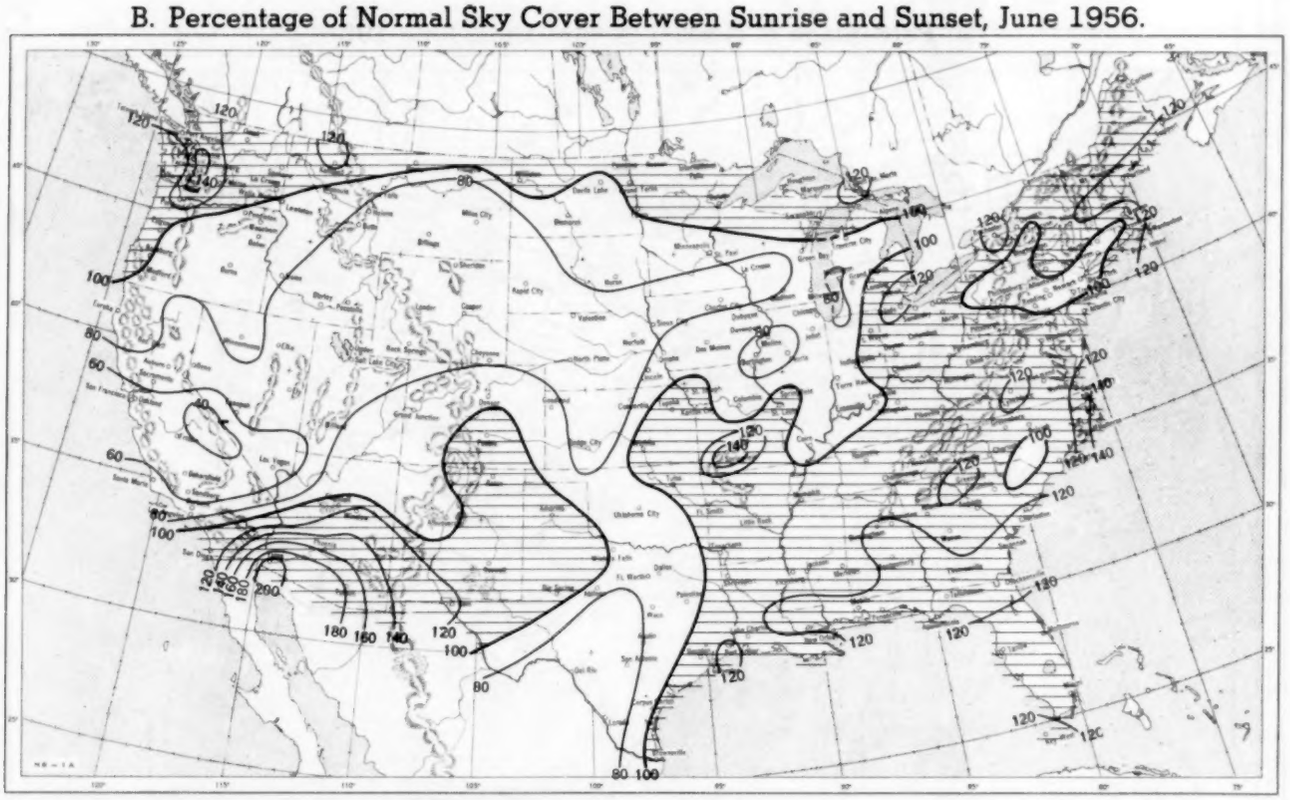


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, June 1956.



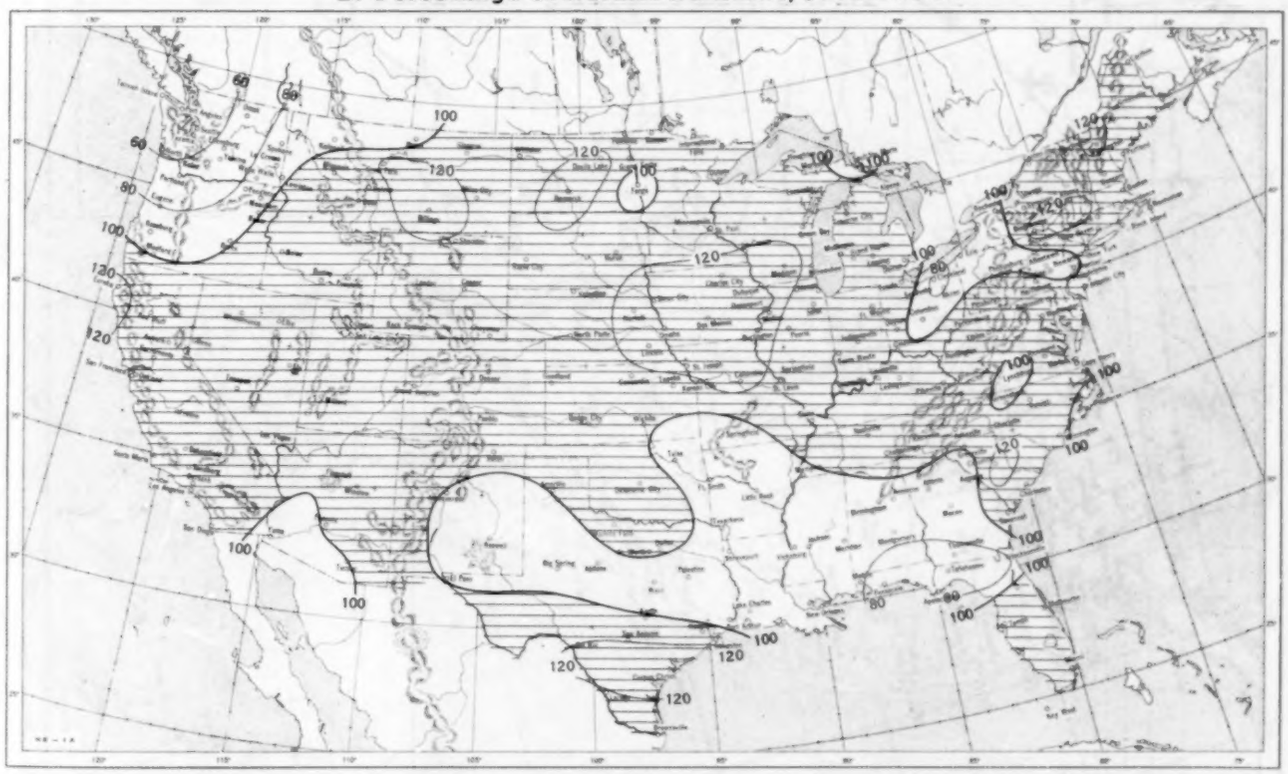
B. Percentage of Normal Sky Cover Between Sunrise and Sunset, June 1956.



A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, June 1956.

B. Percentage of Normal Sunshine, June 1956.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, June 1956. Inset: Percentage of Mean Daily Solar Radiation, June 1956. (Mean based on period 1951-55.)

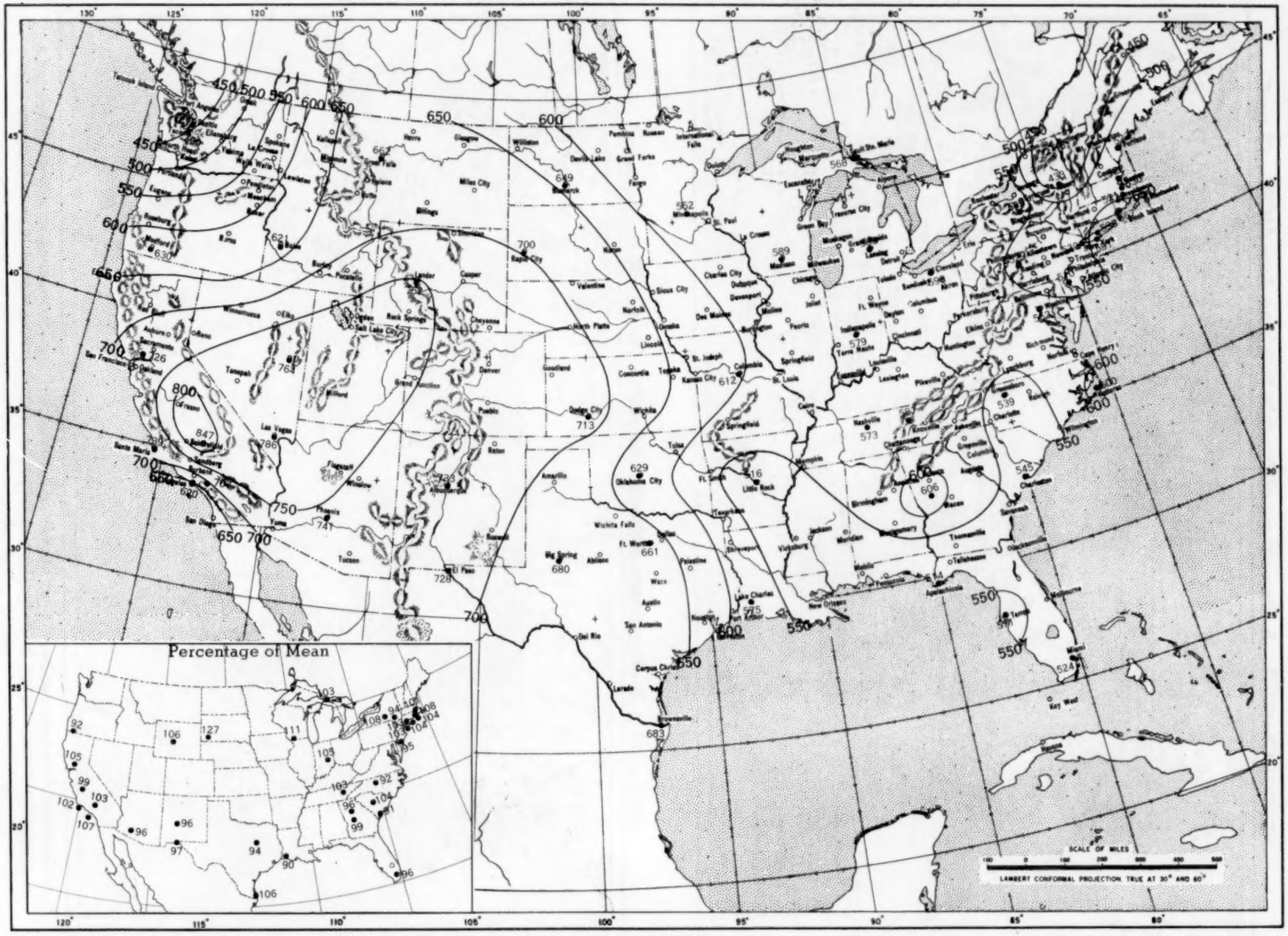
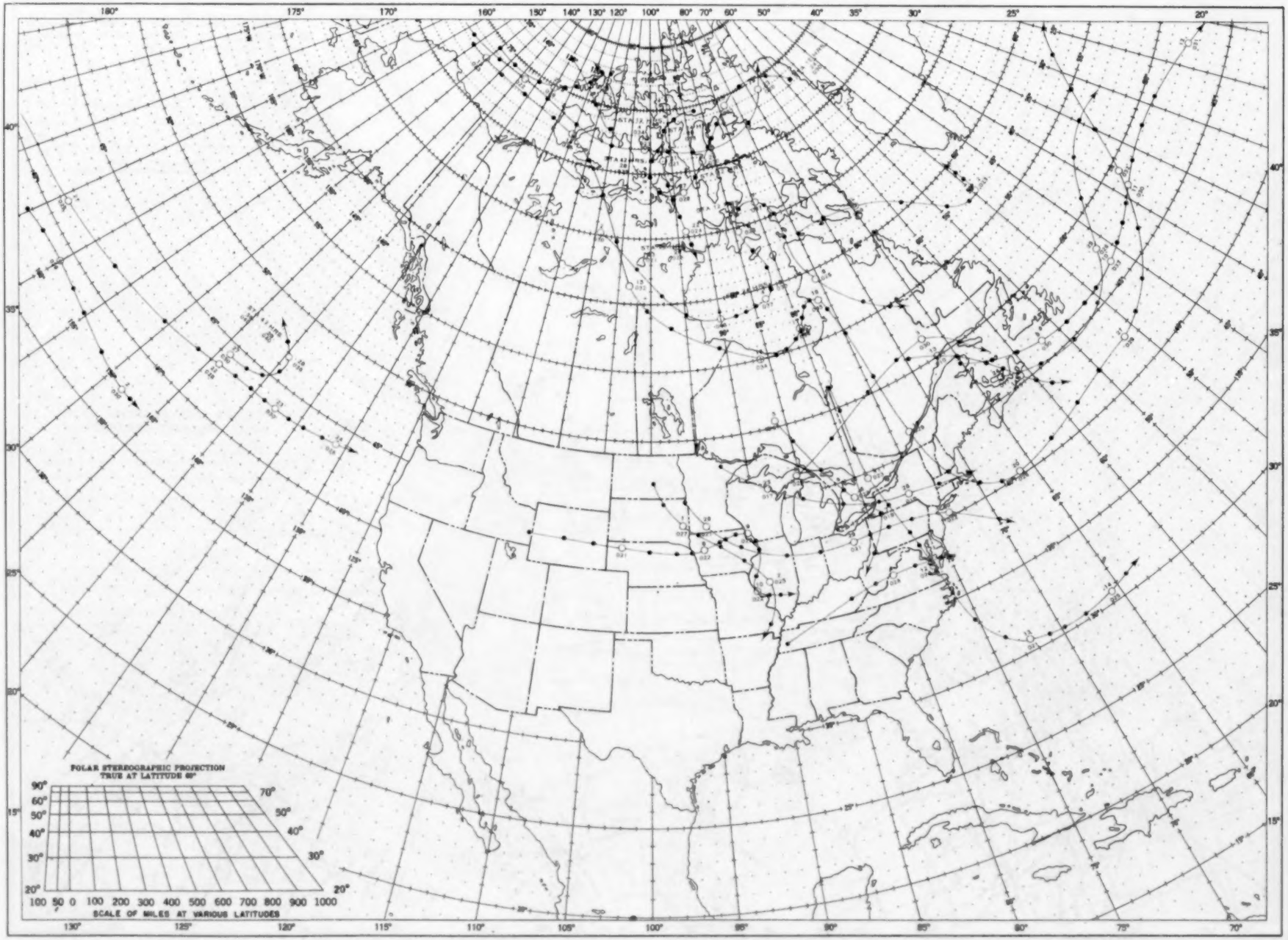


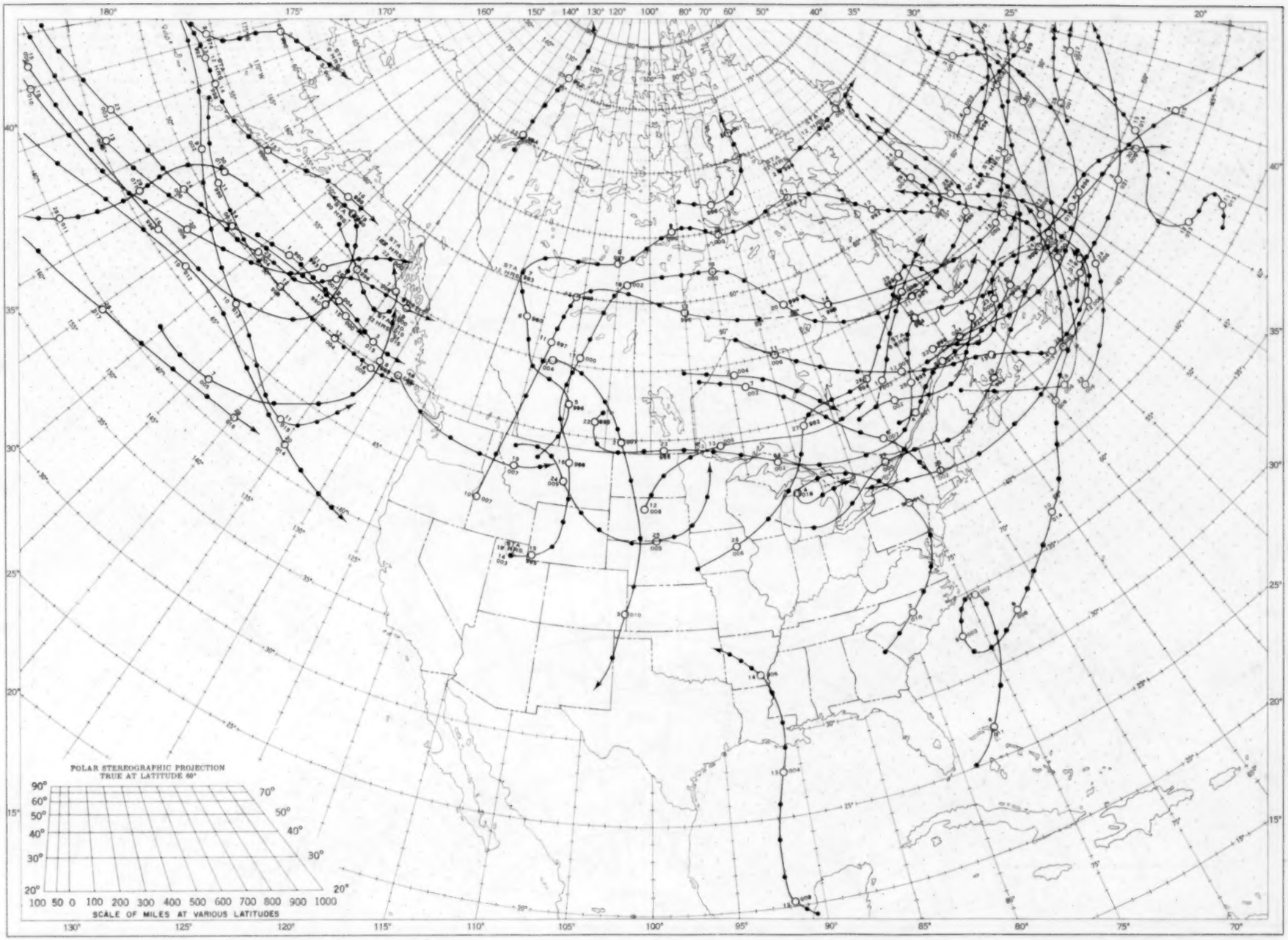
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, June 1956.



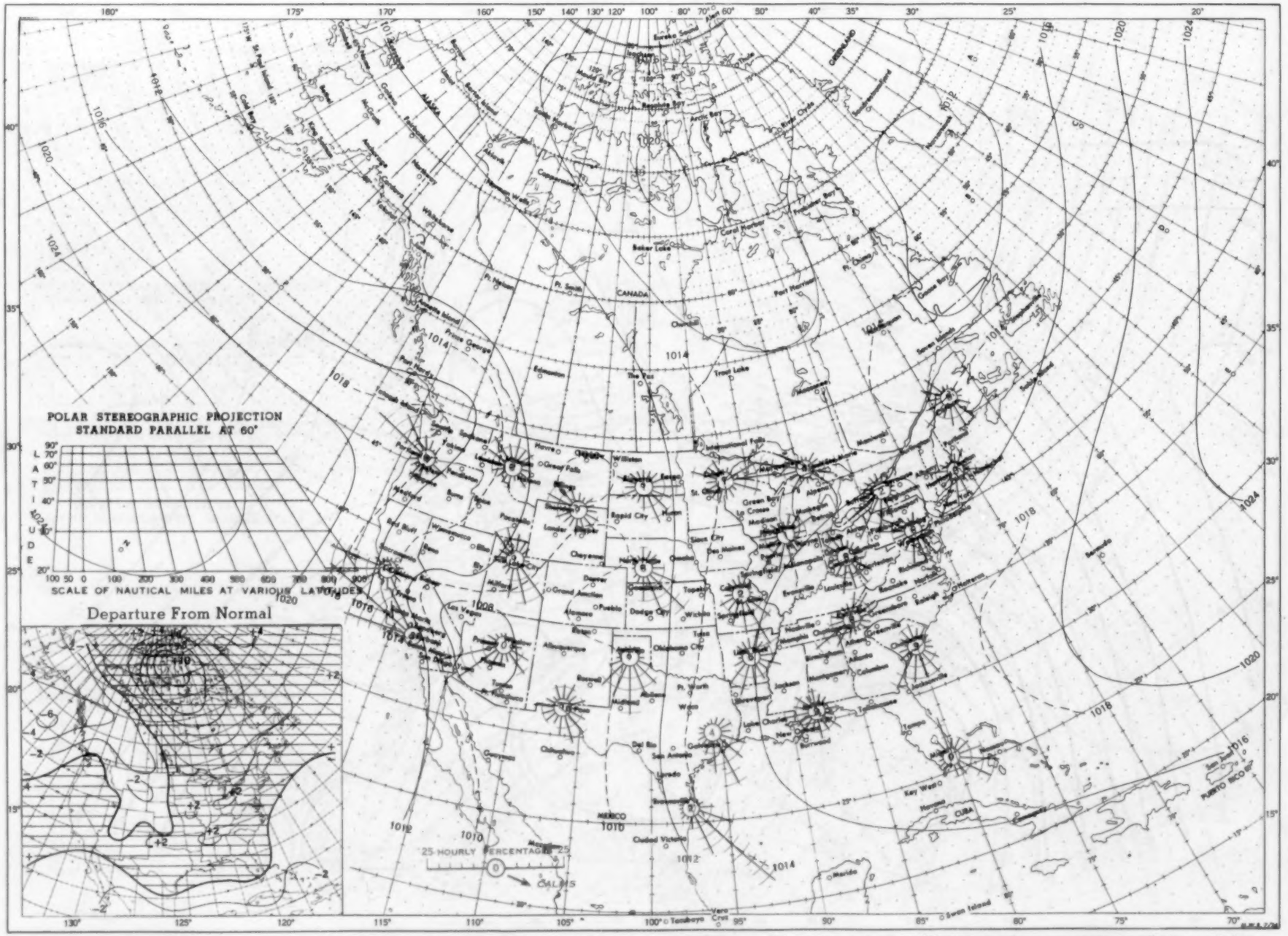
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, June 1956.


POLAR STEREOGRAPHIC PROJECTION
TRUE AT LATITUDE 60°
90° 60° 50° 40° 30° 20°
70° 50° 40° 30° 20°
100 50 0 100 200 300 400 500 600 700 800 900 1000
SCALE OF MILES AT VARIOUS LATITUDES

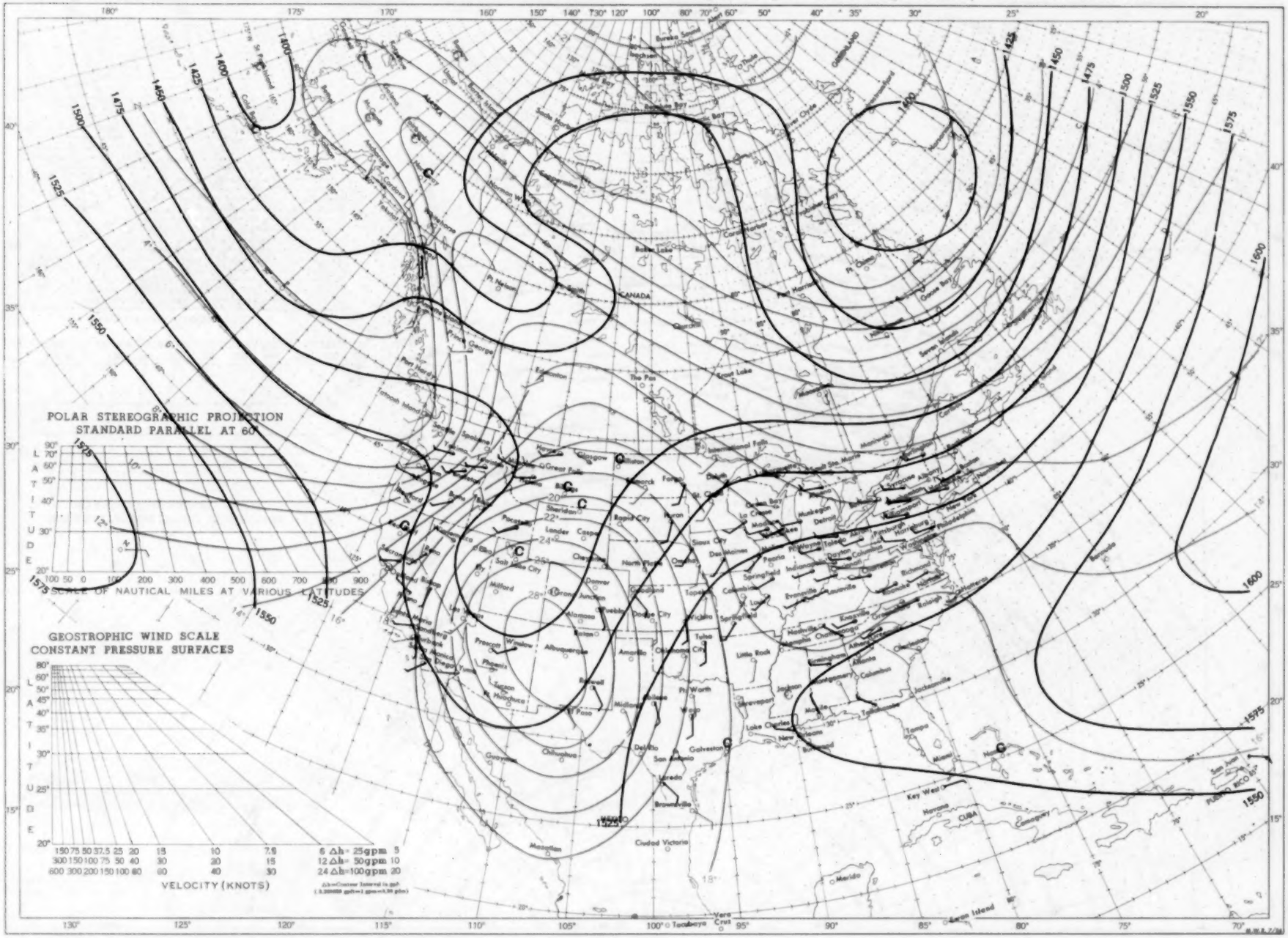
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, June 1956. Inset: Departure of Average Pressure (mb.) from Normal, June 1956.



Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

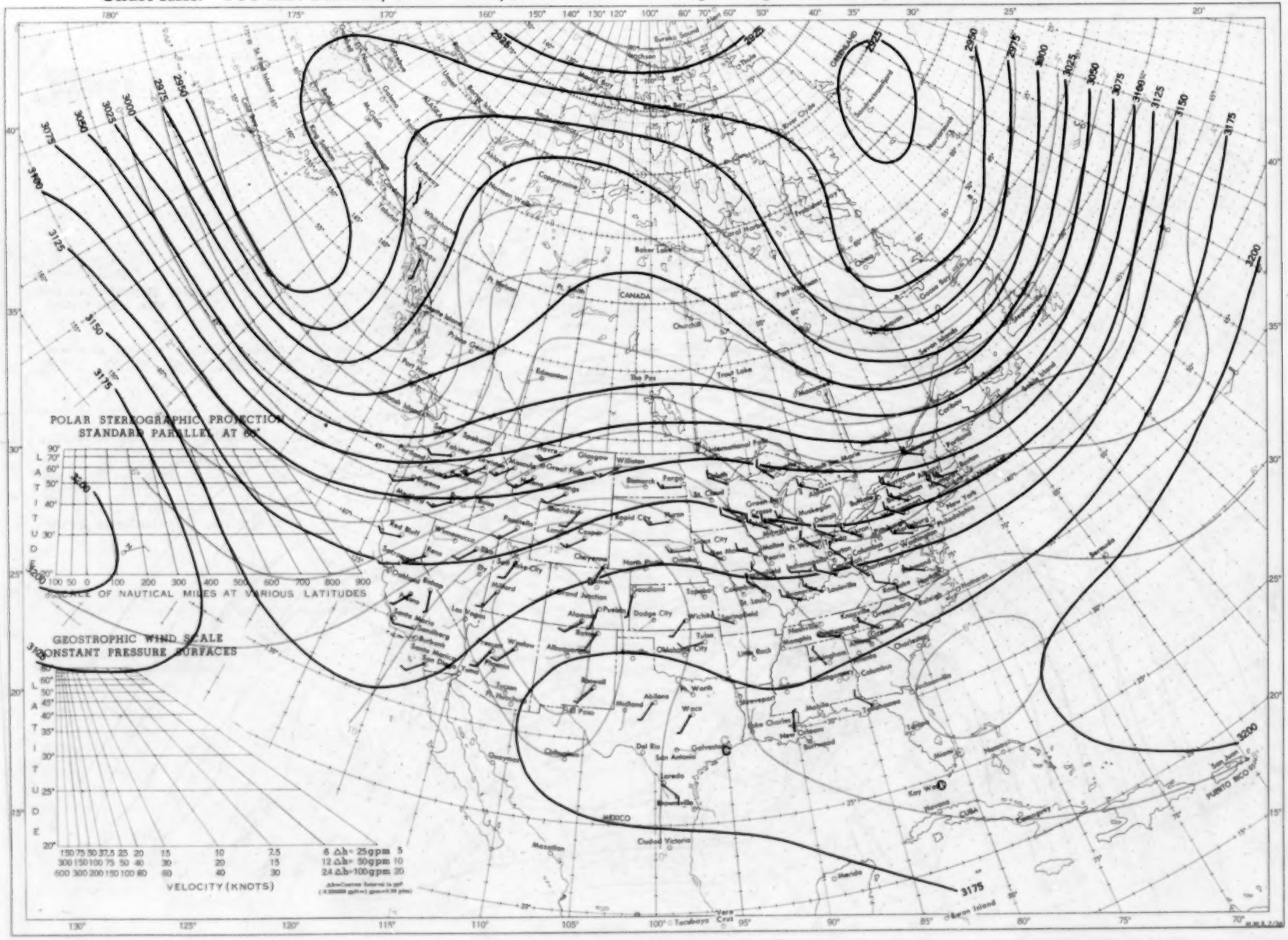
Chart XII. 850-mb. Surface, 0300 GMT, June 1956. Average Height and Temperature, and Resultant Winds.



Height in geopotential meters (1 g.p.m. = 0.98 dynamic meters). Temperature in °C. Wind speed in knots; flag represents 50 knots, full feather 10 knots, and half feather 5 knots. Winds shown in red are based on rawins taken at the indicated pressure surface and time. Those in black are based on pibals taken at 2100 GMT and are for the nearest standard height level.

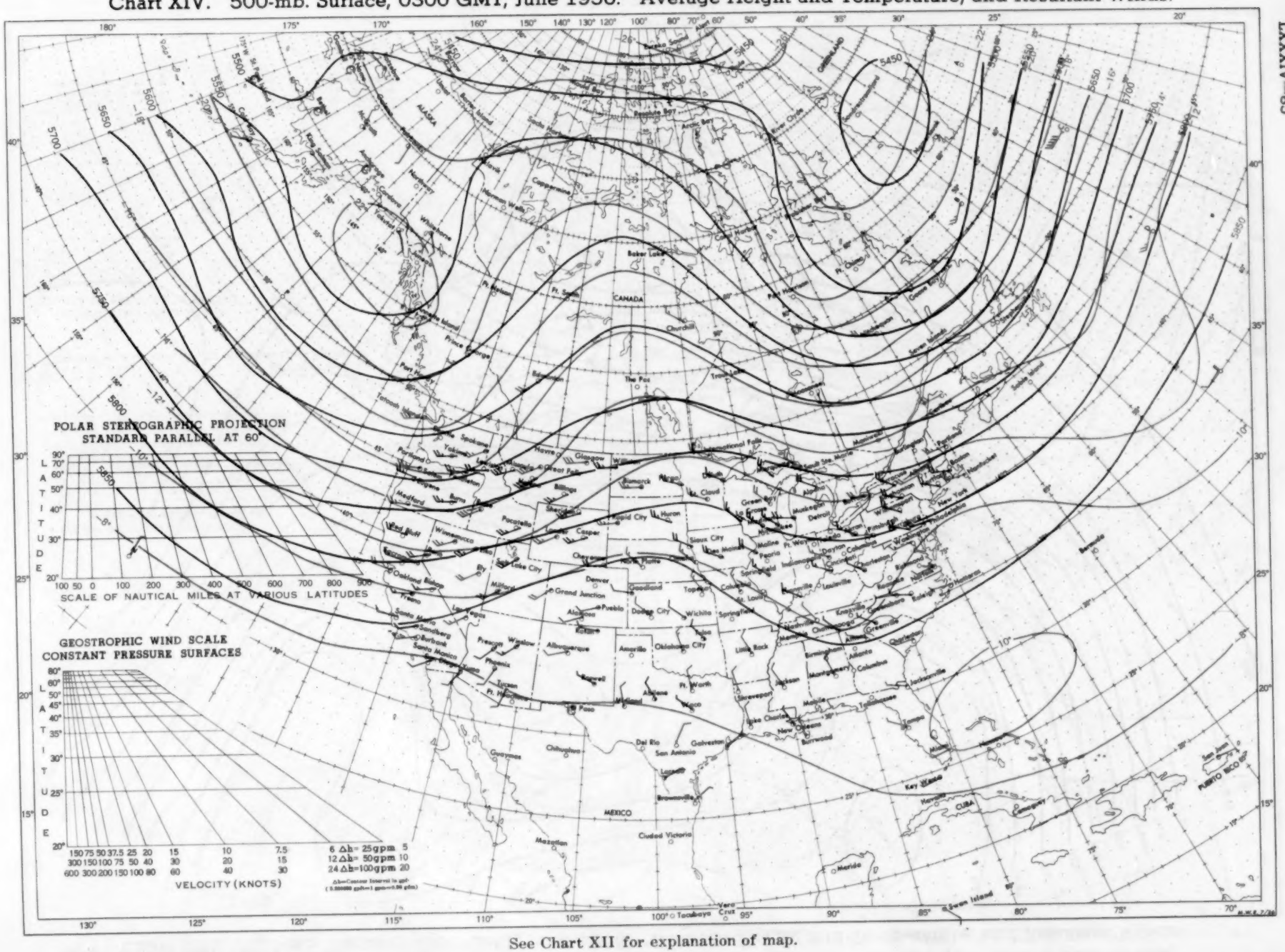
on pibals taken at 2100 GMT and are for the nearest standard height level.

Chart XIII. 700-mb. Surface, 0300 GMT, June 1956. Average Height and Temperature, and Resultant Winds.



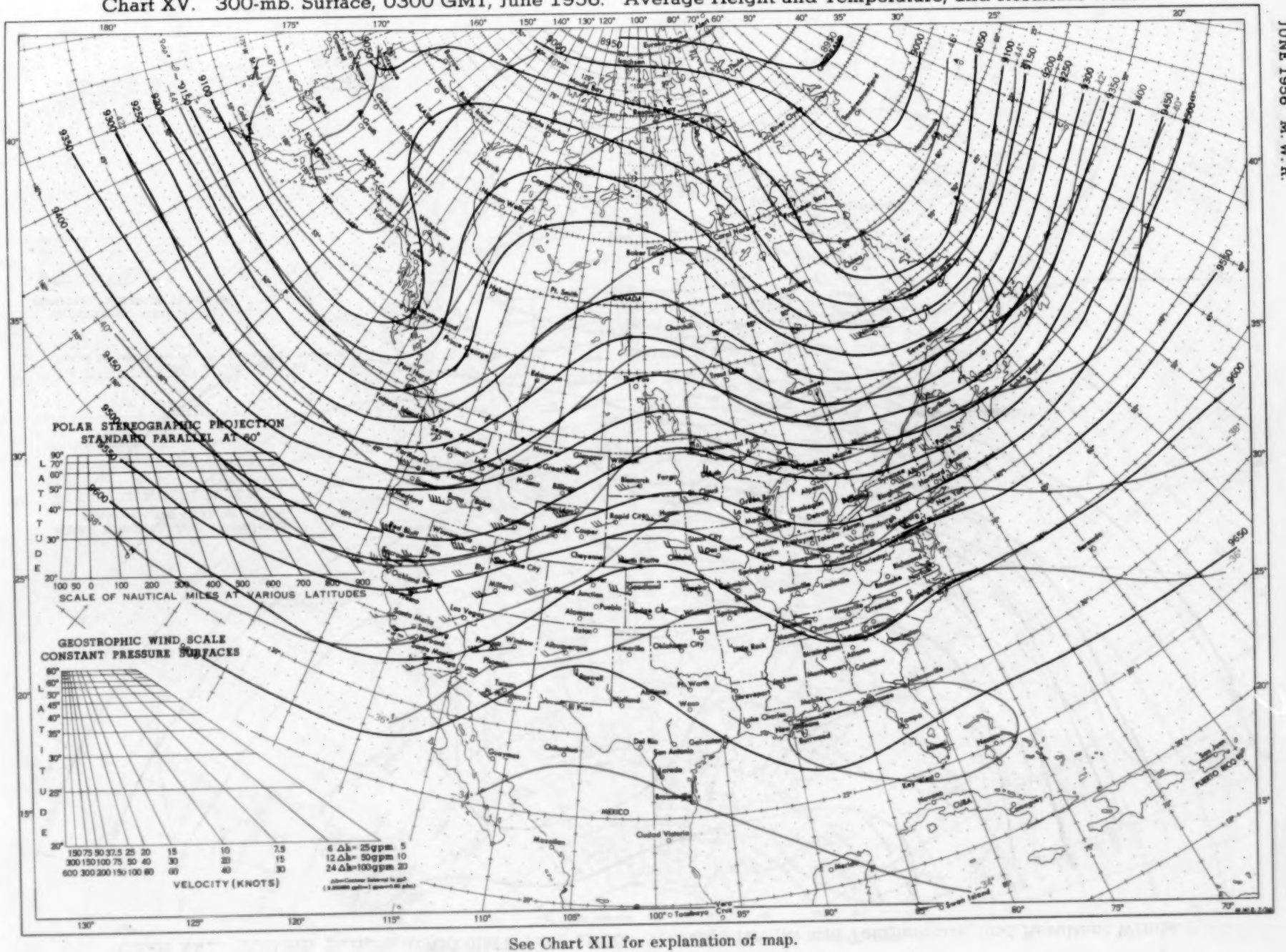
See Chart XII for explanation of map.

Chart XIV. 500-mb. Surface, 0300 GMT, June 1956. Average Height and Temperature, and Resultant Winds.



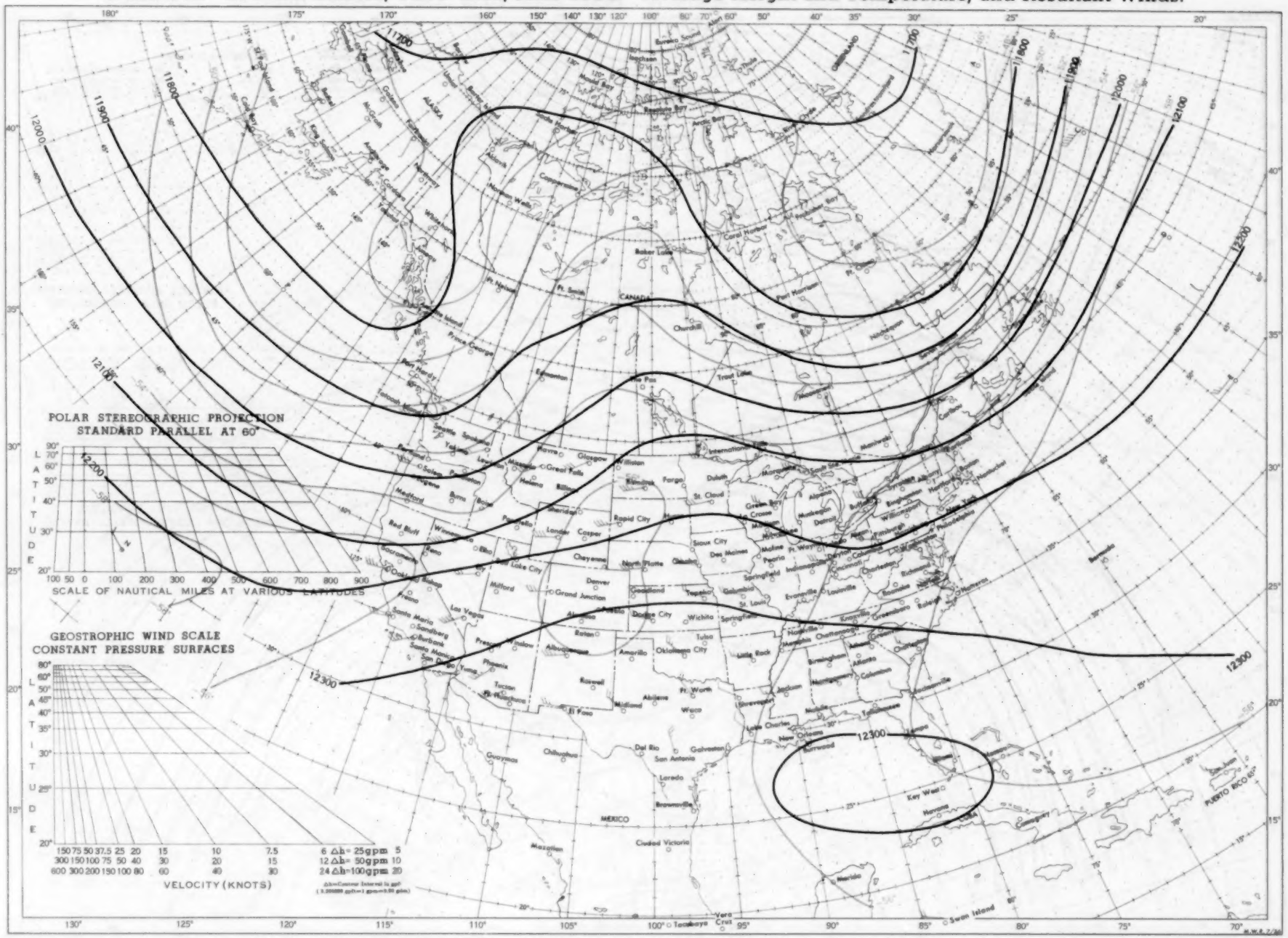
See Chart XII for explanation of map.

Chart XV. 300-mb. Surface, 0300 GMT, June 1956. Average Height and Temperature, and Resultant Winds.



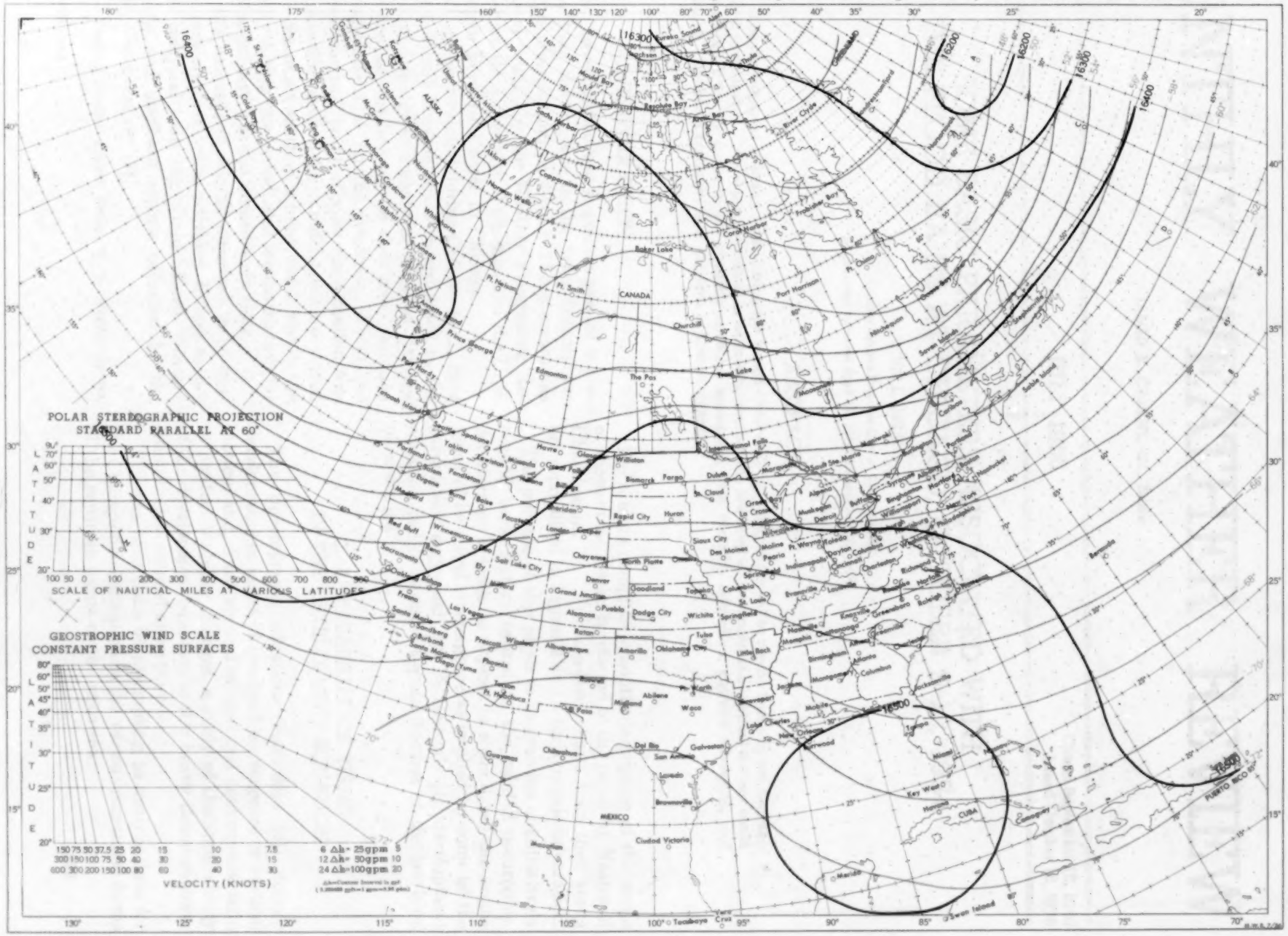
See Chart XII for explanation of map.

Chart XVI. 200-mb. Surface, 0300 GMT, June 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.

Chart XVII. 100-mb. Surface, 0300 GMT, June 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.